Tenth Edition

Farm Power and Machinery Management



Donnell Hunt

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PREFACE

Farm Machinery Management is the section of farm management that deals with the optimization of the equipment phases of agricultural production. It is concerned with the efficient selection, operation, repair and maintenance, and replacement of machinery.

As North American agriculture has developed, it has become increasingly dependent on mechanization. With the technology available today, one farm provides the food and fiber needs of 128 people. Additionally, these farms exported more than 25% of the total value of the production of corn, wheat, and soybeans. Such performance would be impossible without augmenting human strength and energy with farm machinery.

The costs of owning and operating machinery is often exceeded only by the cost of land use. A typical Corn Belt grain farm, 400 ha [1000 a], can have machinery (no labor) costs of $200/ha [$80/a]. Machinery investment costs can be $1200/ha [$500/a]. Potentially, there is opportunity to improve farm profits by reducing machinery costs.

The measure of the worth of a management decision is assumed to be dollar profit. While it is recognized that many farmers use personal preference, comfort, and convenience as deciding factors in machinery management, such emotional responses are ignored in this presentation unless there is an apparent economic benefit. The philosophy adopted is that a farm is a factory that markets several products, and the management goal is to maximize profits. The machines on the farm are merely tools of production and have costs that subtract from gross income. But present and future concerns for the environment and for conservation of natural resources cause activity for farm machinery that may not be strictly economic. In 1997 more than 13,000,000 ha [33,000,000 a] were enrolled in U.S. government conservation programs.

The objectives of this textbook are to analyze the factors that comprise machinery management, to explain the function of the various machines and mechanisms as they affect economic operation, and to indicate approaches and procedures for making management decisions. Farm machinery operation practices are ever changing and are related to both the crop and the geographic area. It is impractical to completely cover the subject in a textbook. It is hoped that instructors using this text can augment the book with material specific for students' needs.

An understanding of agricultural practices, college algebra, and trigonometry should be adequate preparation for using this text. Concepts of economics and physics are developed as needed.

Metric units are used to conform with policy pronounced by the Congress. Customary units are retained in brackets following the SI (Système Internationale d'Unitès) units since it is anticipated that people engaged in agriculture will be using both systems. Units such as litres, kilometres per hour, hectares, and revolutions per minute are not recommended by SI but are used because of their particu-

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lar utility for machinery management. The units have been chosen to reflect the precision of the measurement. For example, tillage depth is reported in centimetres since a field measurement can seldom be determined more closely than a whole centimetre. A description of the SI system of units, abbreviations, and a table of common conversions is included in Appendix J.

The subject matter may be of direct value only to the present or potential farm operator or farm manager. However, the management principles and the machinery operating details should be useful to students preparing for careers in agricultural education, agricultural mechanization, or agricultural business and to the agricultural engineer who might serve as a machinery manager on a large commercial farm.

Students of machinery management are encouraged to procure and study the many excellent informational sales brochures produced by the equipment manufactures that are available at dealerships. Detailed explanations and illustrations, usually in color, show the equipment in much greater detail than can be included in this text.

ACKNOWLEDGMENTS

A compilation of machinery management facts would be impossible without the cooperation of many farm equipment companies, governmental bodies, and technical associations who have supplied data and illustrations. These groups contributed information for this volume.

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ECONOMIC PERFORMANCE

Optimum farm machinery management occurs when the economic performance of the total machine system has been maximized. Admittedly many farm machines are operated for tradition's sake, for pleasure, and even for therapeutic value; however, the successful commercial farm, composed as it is of many enterprises for which machines are only tools of production, will operate its machinery in a businesslike manner to produce goods at a profit.

The performance of a machine system is profitable only when it can add value to products and processes beyond the system's cost of operation. A minimum cost would appear to be an optimum economic goal, but overall profit maximization is the true goal of business and on the farm this does not necessarily occur with a minimum cost system of operations. Profit for the total business should also be foremost at the individual machine level. This may dictate that an individual machine operate at other than its possible minimum cost. Good machinery management, then, requires that the individual operations in a machine system must be adjusted and combined in a manner so that their overall performance returns the greatest profit to the farm business.

The economic performance of a machinery system is measured in terms of dollars per unit of output. Examples are $120 machinery cost/ha of corn harvested, $40/t of soybeans grown, 75¢/kg of beef marketed, etc. (See Appendix L for abbreviations of units.) In these terms maximum system performance occurs when the production cost per unit is lowest.

The three components of economic performance are

1. Machine performance
2. Power performance
3. Operator performance

Sometimes these items are referred to inaccurately as "efficiencies," as if there existed an ultimate value on which some fractional performance could be based. It

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should be manifest that zero cost is the only theoretical limit to the potential economic performance of machine systems, and there is no way to express the efficiency of a machine system in percentages since the output-input ratio is in terms of economic measures to physical factors.

The dimensional units of machine, power, and labor performances are in quantity per time. These three performance figures add to become an economic performance figure when the quantity per time is divided into the cost per time of each component. For example, a machine system produces 5t of forage/hr with a machine cost of $10/hr. The system requires 1.5 work-hours and 1.1 tractor-hours at $8 and $7, respectively. The economic performance of the system is:

$$\underline{5.94}\frac{\$}{t} = \frac{\$10}{hr} \times \frac{1hr}{5t} + \frac{\$8}{hr} \times \frac{1.5hr}{5t} + \frac{\$7}{hr} \times \frac{1.1hr}{5t}$$

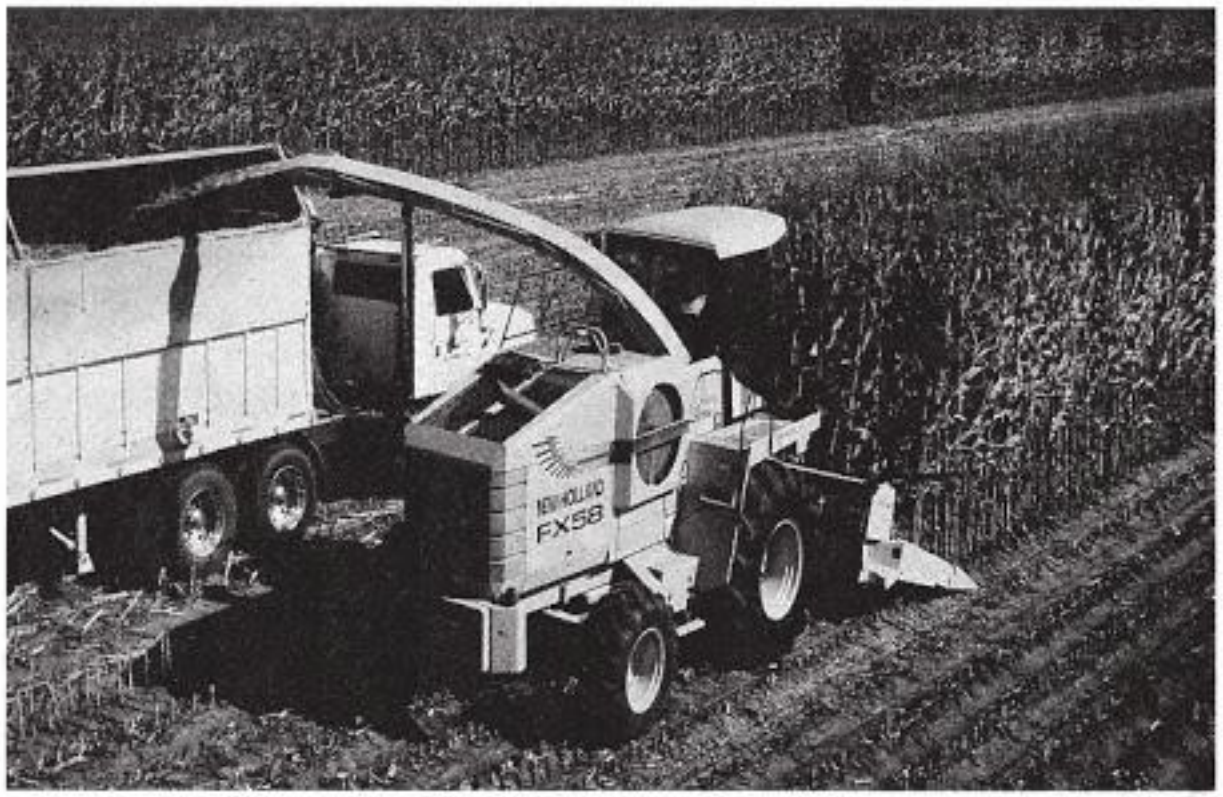
See Laboratory Exercise 1, Problem Solving, to become familiar with the unit factor procedure for making calculations.

Hardware, energy, and human labor and management are the components of farm machinery systems. The economic performance of these components are examined in the next three sections.

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Chapter 1

MACHINE PERFORMANCE



Measures of agricultural machine performance are the rate and quality at which the operations are accomplished. Rate is an important measure because few industries require such timely operations as agriculture with its sensitivity to season and to bad weather. Completeness is that portion of quality describing a machine's ability to operate without wasted product. As most agricultural materials are fragile and many are perishable, the amount of product damage or reduction in product quality due to a machine's operation is another important measure of machine performance. Farm operators are very aware of the need for complete and speedy operations but they often ignore the economic penalties resulting from crop and soil damage. Quality as well as quantity must be considered when evaluating machine performance.

A rate of machine performance is reported in terms of quantity per time. Most agricultural field machine performance is reported as area per hour. Harvesting machine performance is sometimes quoted as bushels per hour; quintals per hour; tons or tonnes per hour; and in the case of balers, bales per hour. Processing equipment performance is usually expressed as bushels or tonnes per hour. Such performance figures are properly called *machine capacity*.

Capacities

Capacity, when expressed only as area per time, is usually not a sufficient indicator of a machine's true performance, particularly with harvesting machines. Differences in crop yields and crop conditions can mean that one machine may have a

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low area per hour capacity but a high mass per hour capacity when compared with an identical machine in a different field. In this case a valid comparative capacity would be mass per hour.

The concepts of weight and mass must be understood for confidence in expressing machine capacities and crop yields in both customary and SI units. *Mass* is to be thought of as the substance of a body that resists acceleration and is attracted to the mass of the earth. A body will accelerate rapidly toward the center of the earth unless restrained. This restraining force is equal to the body's *weight*.

The relationship between mass and weight is

$$f = m\,ac$$

where f = force acting on the body,
m = mass of the body, and
ac = resulting acceleration in units of distance/s^2

When the acceleration is caused by the earth's gravitational attraction, the term, ac, is labeled g and the force, f, is called weight. At sea level, g is considered to be 32.2 ft/s^2 in customary units and 9.807 m/s^2 in SI units. The value of g decreases slightly with elevation above sea level.

Unless measured with a beam balance scales, the weight of a body will vary at different places over the earth; therefore, the SI system uses mass units rather than weight units for measuring quantities of agricultural products. Kilograms, quintals (100 kg), and tonnes (1000 kg—also megagram) are common commercial trade units. These masses are commonly determined, however, by measuring their weights. Balance beam scales (no springs) are to be used for legal trade.

The customary system traditionally determined grain quantities with a volume term, the bushel. In recent years the bushel has come to mean a quantity of produce weighing a designated number of pounds depending on the crop and its moisture content. Some produce and most forages are measured in hundredweight, cwt (100 lb in the United States, 112 lb in England), and in tons, T (2000 lb in the United States, 2240 lb in England).

Combines, potato harvesters, and similar machines that separate desired material from undesirable material need a special capacity comparison term. Rather than a report on the weight of material harvested, the weight of material handled is the proper capacity measure. The term *throughput* has come to mean the time rate of processing a total mass of material through a machine. As an example, the kilograms per hour throughput of a combine is assumed to include the total mass of grain, chaff, straw, and weeds that enter the header. Even throughput is not always a constant base for comparison, as it varies with crop moisture conditions. Throughput capacity ratings should be accompanied by a material moisture report.

Calculations of machine capacity involve measuring areas or masses and times. The computations are relatively easy if attention is paid to units. The units for area in this text are hectares, abbreviated as ha, and acres, abbreviated as a.

As an example case, three types of machine capacity are computed below—field capacity, material capacity, and throughput capacity.

It is determined that a 5-m [16.4-ft] width-of-cut combine is traveling 1.5 m/s [4.9 ft/s] In one minute's time 50 kg [110 lb] of grain are collected in the grain tank and 60 kg [132 lb] of material are discharged out of the rear of the machine.

Machine Capacities

1. Field capacity

$$\underline{2.7}\,\frac{\text{ha}}{\text{hr}} = \frac{1.5\,\text{m}}{\text{s}} \times \frac{5\,\text{m}}{1} \times \frac{1\,\text{ha}}{10{,}000\,\text{m}^2} \times \frac{3600\,\text{s}}{1\,\text{hr}}$$

$$\left[\underline{6.64}\,\frac{\text{a}}{\text{hr}} = \frac{4.9\,\text{ft}}{\text{s}} \times \frac{16.4\,\text{ft}}{1} \times \frac{\text{a}}{43{,}560\,\text{ft}^2} \times \frac{3600\,\text{s}}{\text{hr}}\right]$$

2. Material capacity

$$3000\,\frac{\text{kg}}{\text{hr}} = \frac{50\text{kg}}{\text{min}} \times \frac{60\text{min}}{\text{hr}}$$

$$\left[6600\,\frac{\text{lb}}{\text{hr}} = \frac{110\,\text{lb}}{\text{min}} \times \frac{60\,\text{min}}{\text{hr}}\right]$$

3. Throughput capacity

$$\underline{6.6}\,\frac{\text{t}}{\text{hr}} = \frac{110\,\text{kg}}{\text{min}} \times \frac{\text{t}}{1000\,\text{kg}} \times \frac{60\,\text{min}}{\text{hr}}$$

$$\left[\underline{7.26}\,\frac{\text{T}}{\text{hr}} = \frac{242\,\text{lb}}{\text{min}} \times \frac{\text{T}}{2000\,\text{lb}} \times \frac{60\,\text{min}}{\text{hr}}\right]$$

The capacities just calculated are *theoretical capacities* as distinguished from *effective capacities*. It

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is usually impossible to operate machines continuously or at their rated width of action; therefore, their effective or actual capacities will be substantially less than their theoretical or potential capacities.

Time Efficiency

Time efficiency is a percentage reporting the ratio of the time a machine is effectively operating to the total time the machine is committed to the operation. Any time the machine is not actually processing the field is counted as time waste. Rather strict definitions are required as to what should really be counted as time waste chargeable against the machine. The following list describes the time elements that involve labor, that are associated with typical field operations, and that should be included when computing the capacities or costs of machinery related to the various farm enterprises.

1. Machine preparation time at the farmstead (includes removal from and preparation for storage, also shop work)
2. Travel time to and from the field
3. Machine preparation time in the field both before and after operations (includes daily servicing, preparation for towing, etc.)
4. Theoretical field time (the time the machine is operating in the crop at an optimum forward speed and performing over its full width of action)
5. Turning time and time crossing grass waterways (machine mechanisms are operating)
6. Time to load or unload the machine's containers if not done on-the-go
7. Machine adjustment time if not done on-the-go (includes unplugging)
8. Maintenance time (refueling, lubrication, chain tightening, etc., if not done on-the-go—does not include daily servicing)
9. Repair time (the time spent in the field to replace or renew parts that have become inoperative)
10. Operator's personal time

Not all of these time elements are commonly charged against machine operations. The operator's personal time, 10, is a highly variable quantity and is usually unrelated to the operating efficiency of the machine; consequently, it is often ignored as a time waste charged against the machine. Similarly, 1, 2, and 3 are often excluded from consideration. The remaining elements, 4-9, are the items included in the term *field efficiency*.

Specifically, field efficiency is the ratio of the time in 4 to the total time spent in the field (4-9). Field efficiencies are not constant values for specific machines but vary widely. Table 1.1 lists the ranges for some of the common farm machines.

TABLE 1.1. Range in Typical Field Efficiencies and Implement Operating Speeds

Operation	Equipment	Field Efficiencies, %	Operating Speeds km/hr	[MPH]
Tillage	moldboard plow	88-74	5-9	[3.1-5.6]
	disk harrow	90-77	6-10	[3.7-6.2]
	spring-tooth or spike-tooth harrow	83-65	6-12	[3.7-7.5]
	field cultivator, chisel plow	90-75	6-9	[3.7-5.6]
Cultivation	row crop cultivator	90-68	3-9	[1.9-5.6]
	rotary hoe	88-80	9-20	[5.6-12.4]
Seeding	row planter with fertilizer	78-55	7-10	[4.3-6.2]
	grain drill with fertilizer	80-65	5-10	[3.0-6.2]
	broadcaster	70-65	7-10	[4.3-6.2]
	potato planter	80-55	9-12	[5.6-7.5]
Harvesting	mower-conditioner	95-80	5-9	[3.0-5.6]
	rake	89-62	6-9	[3.7-5.6]
	baler, rectangular	80-65	5-10	[3.0-6.2]
	baler, round	50-40	5-19	[3.0-12.0]
	forage harvester, shear bar	76-50	6-10	[3.7-6.2]
	combine	90-63	3-8	[1.9-5.0]
	corn picker	70-55	3-6	[1.9-3.7]
	windrower, swather	85-75	6-10	[3.7-6.2]
	potato harvester	90-50	3-6	[1.9-3.7]
	cotton, spindle picker	90-65	3-5	[1.9-3.1]
Miscellaneous	sprayer	80-55	7-10	[4.3-6.2]
	anhydrous ammonia applicator	65-55	6-9	[3.7-5.6]
	rotary stalk chopper, mower	85-65	6-10	[3.7-6.2]
	fertilizer spreader	90-60	6-10	[3.7-6.2]

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With a field efficiency established, an equation for effective field capacity can be determined:

$$C = \frac{S w e}{c} \tag{1.1}$$

where C = effective capacity, ha/hr [a/hr]
S = speed, km/hr [mi/hr]
w = rated width of implement, m [ft]
e = field efficiency as a decimal
c = constant, 10 [8.25]

Because traditional land measure is not expected to change, American farmers may be faced with operating metric machines in fields having areas expressed in acres. An approximate equation in the same form as Eq. 1.1 gives the customary capacity of a metric machine as a/hr = S w e/4.

An expression for effective material capacity can be derived from Eq. 1.1 by incorporating a yield per area term in the numerator. If this term should be tons per hectare, the machine capacity will be expressed in tons per hour, etc.

$$M = \frac{S w e y}{c} \tag{1.2}$$

where M = material capacity, units/hr
y = yield, units/area

The suggested time increment in the SI system is the second, and velocities are to be reported as metres per second. However, farm machine speeds have traditionally been reported on an hourly basis as in the customary unit, miles per hour. It is anticipated that the hour unit will persist as the more practical unit for agriculture and thus the field speeds reported in this book will be kilometres per hour. To calculate speeds in metres per second, the kilometres per hour speed is divided by 3.6.

A more precise mathematical statement of field capacity for normally operated machines (without breakdowns or unexpected stoppages) can be developed without reference to such an all-inclusive and general term as field efficiency. Eq. 1.3 applies when only turning time, swath overlap, and such area-related times as filling seed boxes, unloading grain tanks, or unhitching yield-collecting wagons detract from machine performance. A rectangular field with headlands is assumed.

$$C = \frac{S w L E_w}{(c1) L + D S w L E_w + (c2) S t} \tag{1.3}$$

where C, S, w have the same units as in Eq. 1.1
E_w = effective swath coverage, decimal of rated width
D = unproductive time, hr/ha [hr/a]
L = length of field, m [ft]
t = turning time, s/turn
c1 = constant, 10 [8.25]
c2 = constant, 2.7778 [12.1]

As can be intuitively deduced, Eq. 1.3 shows that long fields, quick turns, wide machines, fast speeds, and short loading and unloading times all contribute to high machine capacities.

Factors affecting field efficiency are

1. Theoretical capacity of the machine
2. Machine maneuverability
3. Field patterns
4. Field shape
5. Field size
6. Yield (if a harvesting operation)
7. Soil and crop conditions
8. System limitations

Each of these factors is discussed in turn.

Theoretical Capacity

Field efficiency decreases with increases in theoretical capacity. One can feel intuitively that a minute wasted with a large machine represents more loss in potential production than the same minute lost with a smaller machine. An example case was the study by K. K. Barnes, T. W. Casselman, and D. C. Link (Iowa State University). They found that increasing the width of a 4-row implement by 50% will increase the effective field capacities by only 35% for corn planters and by only 40% for cultivators.

Field capacity of an implement also depends on its travel speed, and one can expect a drop in field efficiency when the implement's operating speed is increased. Increased field speeds will decrease the actual working time required; but if the time losses remain essentially the same, mathematically the field efficiency will be less. Such a result suggests that as far as speed considerations go, it is not good management to try to maximize field efficiency—i.e., one should not use slow speeds to keep the numerical value of field efficiency high. As high field and material capacities are possible with fast ground speeds, the good operator will test and judge the crop and soil conditions and then operate as fast as possible

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without having the quality of the operation suffer to any great extent.

Field speeds may be limited by any of the following factors:

1. Overloading the machine's functional units
2. Inability of the operator to steer the machine accurately
3. Loss of function and structural damage to the machine due to rough ground surface
4. Need to handle materials gently (slowly)

Machine Maneuverability

Farm machines need to be easily maneuvered both in the field and on the road to the field. Field machines need to be designed to permit them to make short turns at the ends of the field and while following crop rows planted on the contour and in curves.

Considerable time and space are required to turn large machines at a headland (Fig. 1.1). Yet the total field turning time for large machines is slightly less than for smaller machines if the large machine can negotiate a turn within the same multiple or fraction of its width as the smaller machine, because the large machine makes fewer turns than the smaller machine in equivalent fields.

The turning radius of implements is an important factor affecting the time lost in end travel and at corners. The automotive and farm equipment industries generally define turning radius as the radius of the circle within which the vehicle can make its shortest turn. Such a definition really reports the radius of the path of an extreme part of the vehicle, R, and usually does not describe the outer radius, r_0, of the machine's working head (as illustrated for a self-propelled combine in Fig. 1.3).

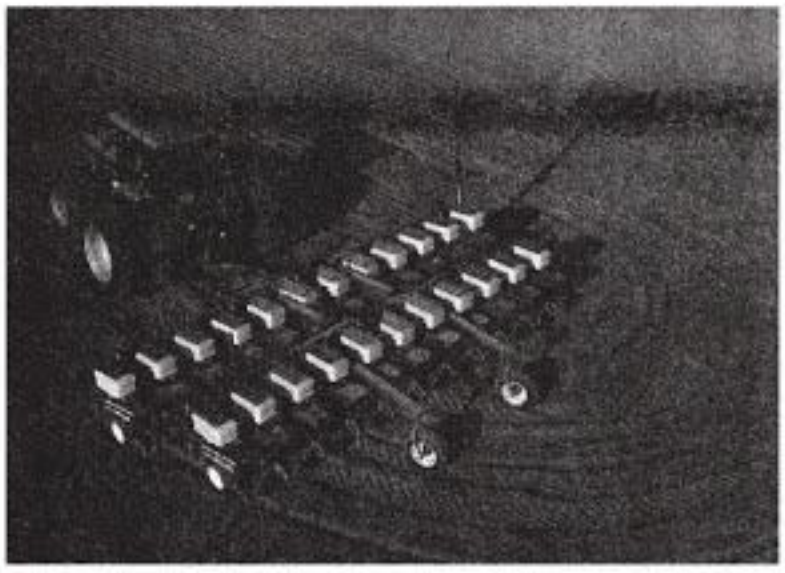


Fig. 1.1. Maneuverability is important for efficient use of large machines.

In this presentation the term *turning radius* will refer to the outer radius of the effective path of the implement when in its sharpest turn, and it shall be designated r with the implement engaged and r_0 with the implement disengaged. The former is usually substantially larger than the latter.

The radius, r, is of most concern to the machine operator in irregular or contoured fields. The radius, r, may be greater than R for a row planter if the effective width of the planter is wider than its frame, or it may be much less as in the case of a side-mounted tractor mower.

Square Corners

Few tillage or seeding machines can make square turns. With most cutter bar mowers the turning radius is short enough to permit square corners. The succeeding raking, windrowing, and baling operations, however, usually follow a rounded corner pattern.

Trailed harvesters can make an essentially square corner if the hitch will clear the tractor wheels in a tight turn. Fig. 1.2 indicates the paths of various points of a tractor and a trailed, offset harvester as they negotiate a corner. This diagram assumes that the operator can start the turn by instantly pivoting the tractor about its right rear wheel; hold this pivot until impending fouling occurs between the tire and the implement tongue, point A; continue the turn from point A to point B holding a near-rub position between the tire and tongue; pivot about the left rear wheel of the tractor from points B to C; and then continue in a straight line at right angles from the original direction of travel. For the implement shown, the turn must start about 0.6 m [2 ft] before the cutter bar cuts out of the crop. Note that the corner remaining is not exactly square and a small area is missed by the left divider of the cutter bar. Also note that the tractor front wheels are driven to the edge of the standing crop at B and as the outer edge of the cutter bar swings from A to C it will back over a portion of the uncut crop.

Diagrams such as Fig. 1.2 and 1.3 are about the only way of predicting the turning ability of farm implements. One may assume that turns are applied instantly. Such an assumption is not unrealistic for slow-moving implements and implements equipped with quick-acting power steering.

Each part of an implement in a turn instantaneously rotates about a common point called a *turning center*.

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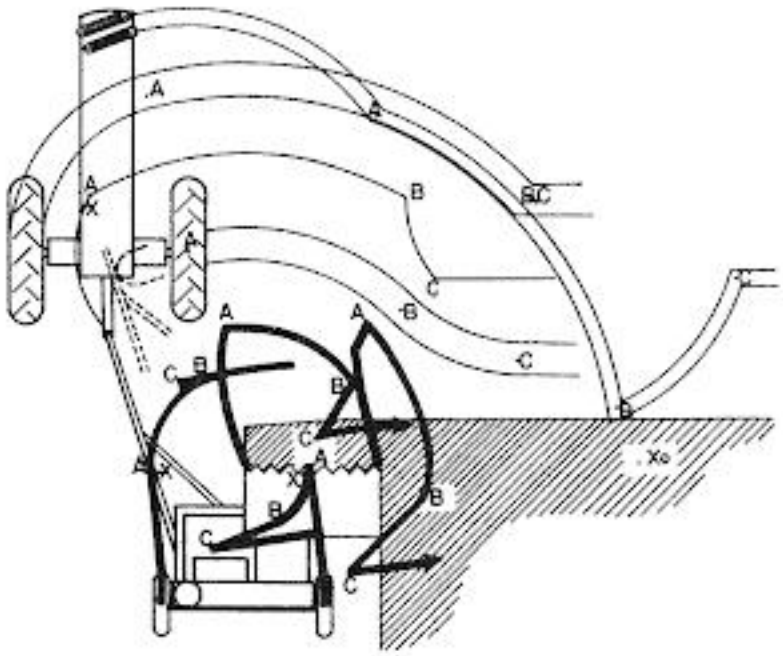


Fig. 1.2. Turning diagram of trailed, offset harvester.

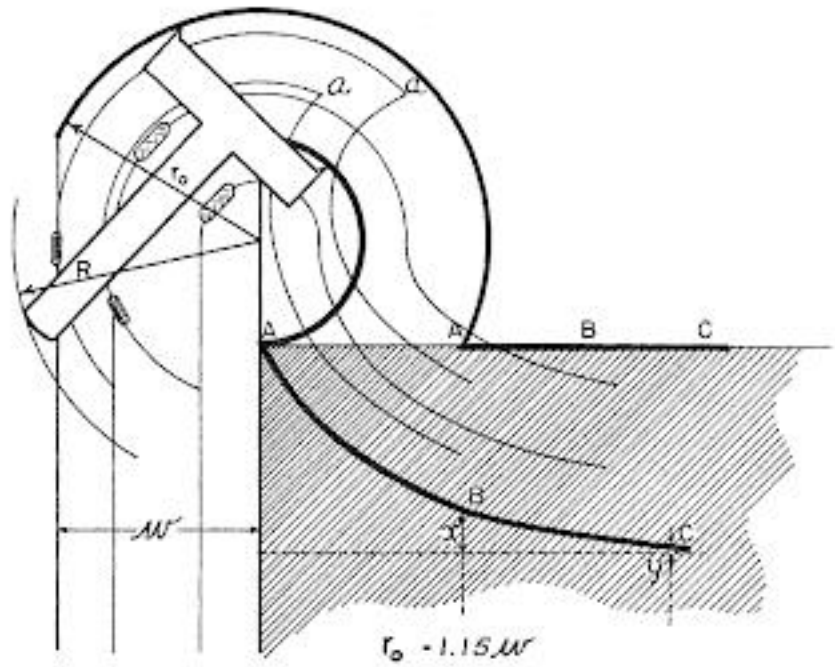


Fig. 1.3. Self-propelled combine at p/2-rad [90°] corner.

The location of this turning center may change quite rapidly as the turn progresses. In Fig. 1.2 the turning center for the implement at the start of its turn is located by the intersection of a line along the implement's axle and a line from the pivot point of the tractor through the drawbar pin. As the turn progresses to point A the turning center gradually moves to the left. It goes off the diagram and goes to infinity when the drawbar pin is about halfway to point X. As the turn progresses farther the turning center comes from infinity on the right and is located at point X_0 when the drawbar pin is at point X. From points A to B the tractor and implement have a fixed angular arrangement; consequently, the turning center is a fixed point at the intersection of lines along the axles of the tractor and the implement. This fixed turning center is located approximately at the position of the left end of the cutter bar when it first starts the turn.

When the turning center is not fixed, very small incremental plottings of the position of the points of interest are necessary to obtain accuracy. The locations of these points are determined by compass arcs from the instantaneous turning center and the arbitrarily advanced position of a significant point. In Fig. 1.2 the drawbar pin was used as the significant point from which all other points were determined.

Self-propelled (SP) implements, particularly those with rear wheel steering, have some unique turning problems. Some self-propelled windrowers have the ability to pivot about the midpoint of their drive axles, as the direction of rotation of their drive wheels can be reversed. A square corner is easily produced.

Self-propelled combines with a minimum turning radius equal to 1.15 their width of action are not capable of maintaining a square corner, as shown in Fig. 1.3. The paths of the left and right divider points of the cutter bar are indicated by heavy, dark lines. (It is assumed that any part of the crop bracketed by these points will be harvested.) After the combine has cut through the corner of the crop and pivoted until the divider points are at points *A* and *A*, the operator must instantly turn the rear wheels at points *a* and *a* from full right to full left. The remainder of the turn is accomplished holding the left divider along the edge of the standing grain while the right divider pivots into the standing grain. Even with such an extreme maneuver the cutter bar is unable to assume a full-width cut until it is beyond point C. On the next round the combine will have to proceed the additional distance x before making the pivot and will be short by the distance *2y* of taking the required width of cut at the new point C. Consequently, the corner becomes progressively sharper each round and additional time will be required when finishing the field.

A comparison of the time lost between the 3π/2-rad [270°] left turn and the π/2-rad [90°] right turn shows that the π/2-rad [90°] turn of Fig. 1.3 will be the most efficient. As given in the development of Eq. 1.13, the unproductive distance traveled by the outside divider point for a 3π/2-rad [270°] turn is $2r_0 - w + 3\pi/2r_0$. The same distance for the π/2-rad [90°] turn is $w + x + (n-1)y + \pi r_0$ where n equals the number of the round. As in Fig. 1.3 where $r_0 = 1.15w$, the distance for the 3π/2-rad [270°] turn becomes 6.7w and for the π/2-rad [90°] turn becomes 4.84w when

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n = 2, x = 0.2w, and y = 0.03w. If the travel speeds for the two turns are essentially the same, one could make approximately 64 rounds before the time for the π/2-rad [90°] turn would be as much as that for the 3π/2-rad [270°] left turn. At such a time only three or four extra passes would be required to even up the corner. Remember that the x and y distances in Fig. 1.3 are the shortest possible. If the operator is unable to produce a turning radius of 1.15w, the efficiency for the π/2-rad [90°] turn will descend to that of the 3π/2-rad [270°] turn.

Curved rows and fields planted on contour lines restrict machine use. Fig. 1.4 shows a vehicle with wheel spacings twice the row spacing, s, negotiating a curve keeping a clearance, c, between the row and the center of the wheel. The vehicle wheelbase, L, must be no greater than $(s^2 + 2\,Rs - 2sc - 4Rc)^{1/2}$ to make the curve successfully. Tractors or self-propelled implements with tricycle configuration are slightly more adept in these turns.

Transport of machines over roads should be rapid, convenient, and safe. Some wide implements are made more maneuverable by folding to smaller widths (Fig. 1.5). Very large and heavy implements use the tractor's hydraulic power to do the folding. Other designs readjust the hitch to permit trailing wide implements in a lengthwise manner (Fig. 7.3).

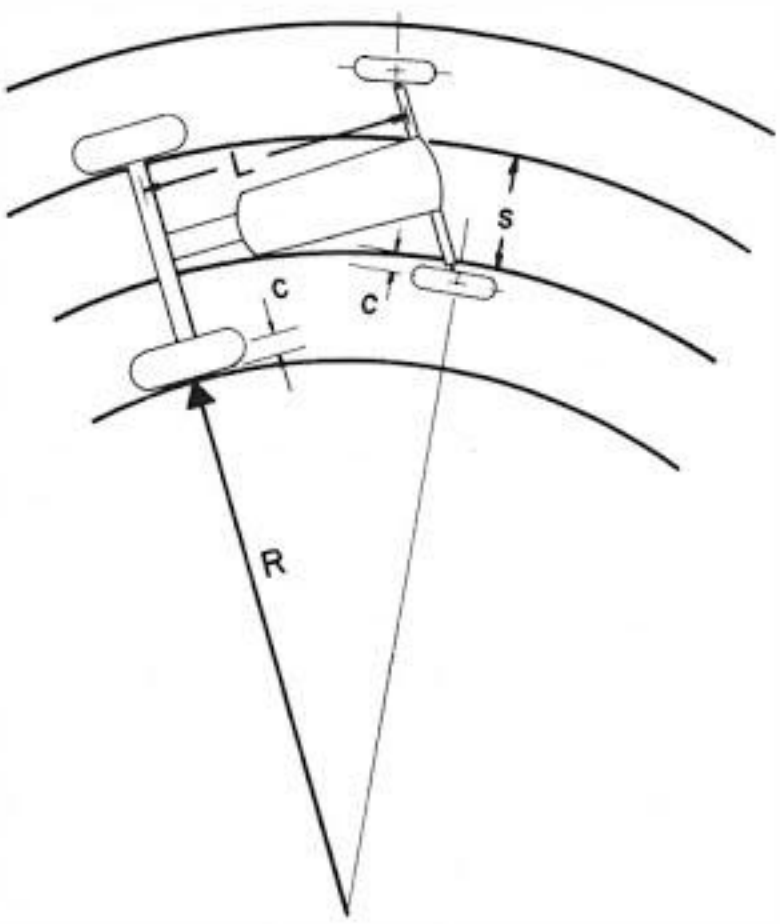


Fig. 1.4. Limiting-row curvature for vehicle with 2s wheel spacing.

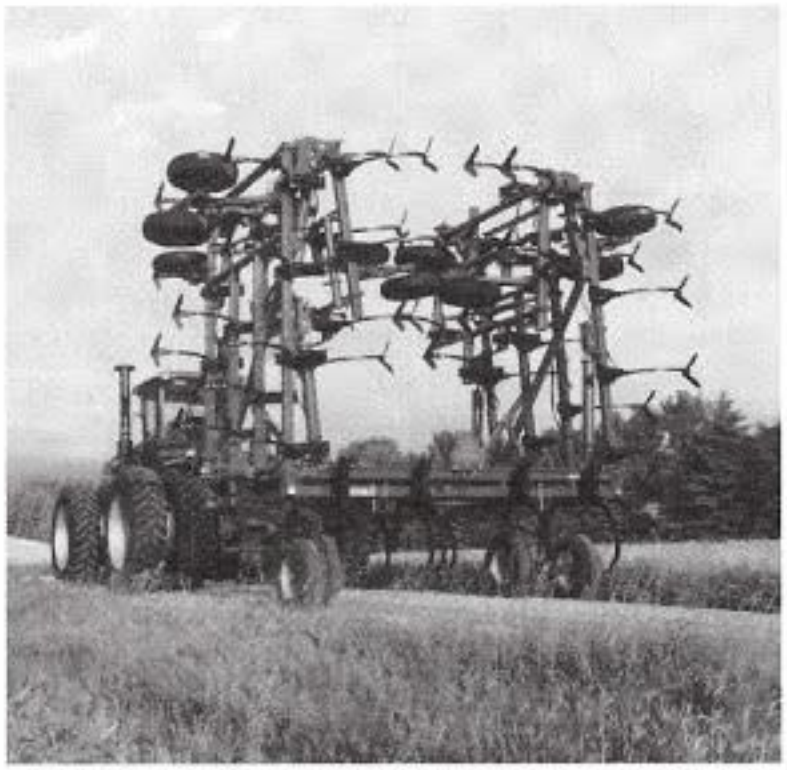


Fig. 1.5. Implement folded for transport.

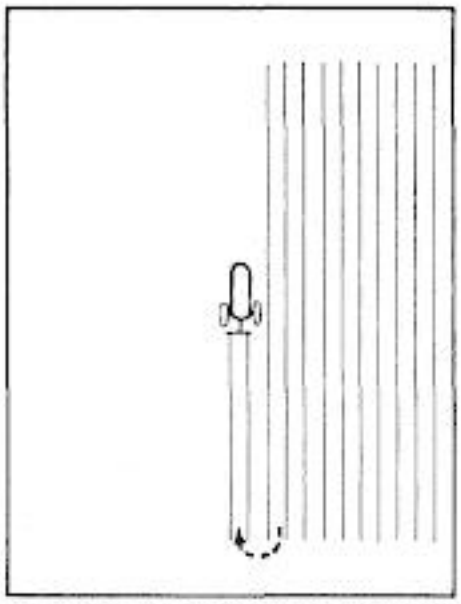


Fig. 1.6. Twelve-bottom moldboard plow's width reduced by one-third for road travel.

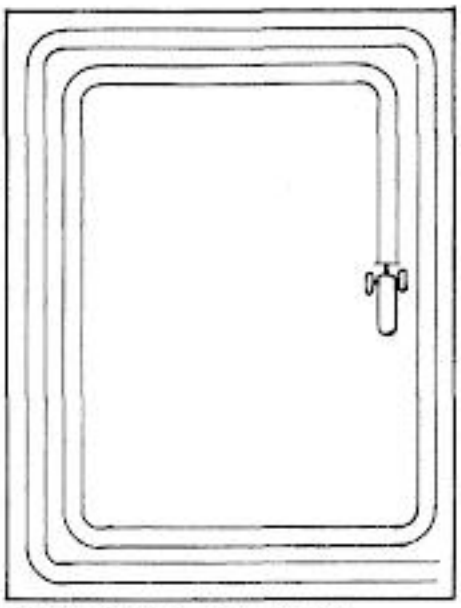
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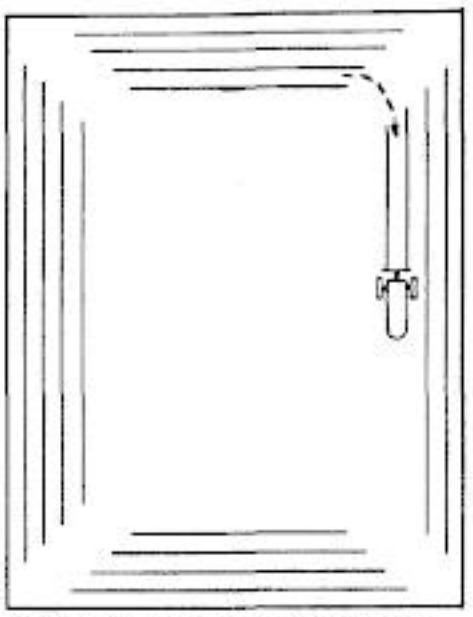
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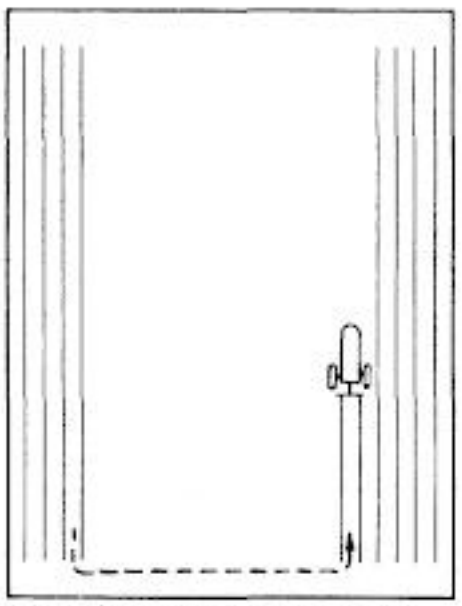
CONTINUOUS, TURN STRIPS AT EACH END



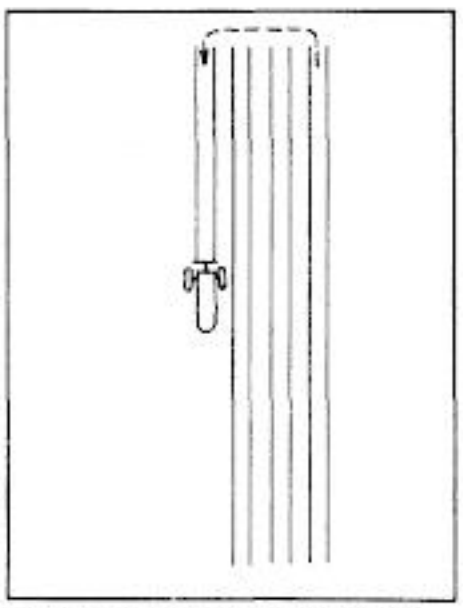
CIRCUITOUS, ROUNDED CORNERS



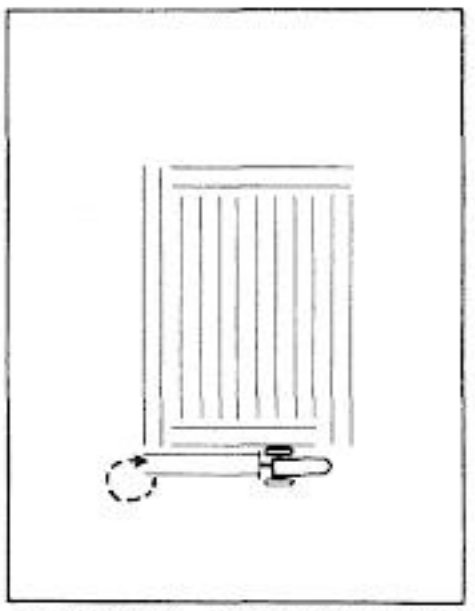
CIRCUITOUS, TURN STRIPS AT CORNER DIAGONALS



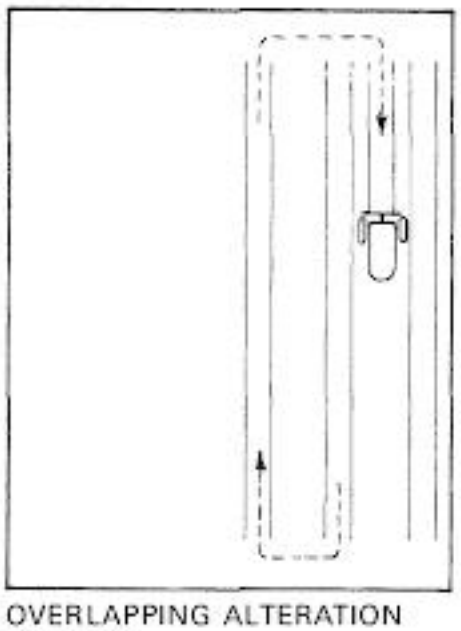
HEADLAND PATTERN, FROM BOUNDARIES



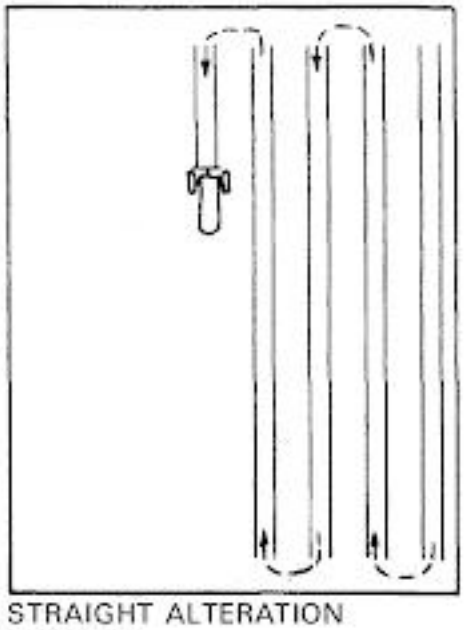
HEADLAND PATTERN, FROM BACK FURROW



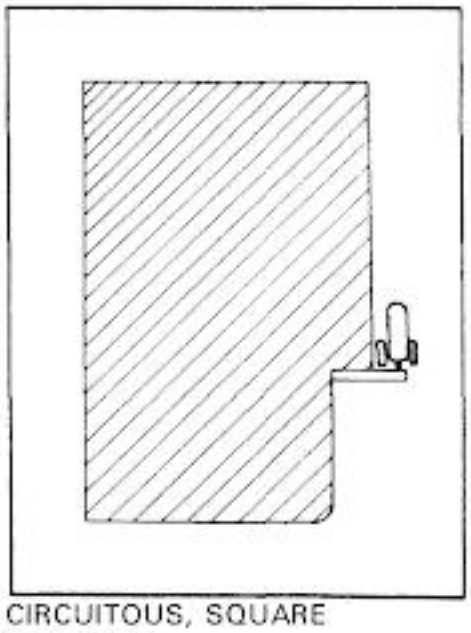
CIRCUITOUS, 270° TURNS FROM BOUNDARIES OR CENTER



OVERLAPPING ALTERATION PATTERN



STRAIGHT ALTERATION PATTERN



CIRCUITOUS, SQUARE CORNERS

Fig. 1.7. Common field machine patterns for rectangular fields.

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Headland Pattern

Laying out the most efficient number of lands for the headland pattern is a common plowing problem. If the lands are made too large, excessive headland travel results. If the lands are made too small, excessive time is used to finish off the numerous dead furrows. Maximum efficiency will lie somewhere between these extremes.

The variables to be considered are

w = effective width of plow, m [ft]
f = length of furrow, m [ft]
S_p = speed of plowing, km/hr [MPH]
S_e = effective speed of headland travel, km/hr [MPH]
W = width of field, m [ft]
L = length of field, m [ft]
c3 = constant, 1000 [5280]

It is assumed that both back-furrowed and dead-furrowed lands are of equal size and one additional trip across the field is required to finish a dead-furrowed land. (Finishing a land includes plowing some of the soil back into the exposed furrow to partially level the soil surface.) The procedure for a 2-back-furrowed field or a 3-land field is illustrated in Fig. 1.8. As shown, the back-furrowed lands have been completed and the dead-furrowed land remains.

Computation of pattern efficiency (PE) requires the calculation of time spent for plowing, for idle travel, and for finishing the dead furrows. The time required for plowing the headlands is not considered in the determination of number of lands, as this time is constant regardless of the number of lands used.

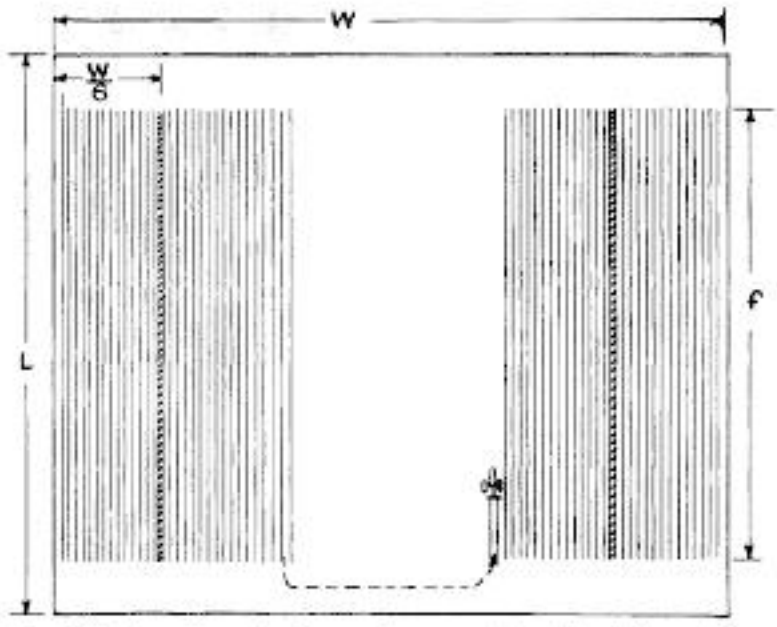


Fig. 1.8. Headland pattern. Average headland travel is W/6 for 2-back-furrowed, 3-land pattern.

Number of back-furrowed lands = n, number of dead-furrowed lands = n − 1, and total number of lands = 2n − 1

Time in hours for one trip (also time to finish a dead furrow) = $f/[(c3)\,S_p]$

Number of trips to complete lands = W/w

Total hours for plowing lands = $f\,W/[(c3)\,S_p\,w]$

Average distance for turning one end of land = 1/2 land width

Width of land = W/(2n − 1)

$$\text{Average time for turning end} = \frac{W}{2(2n-1)(c3)S_e}$$

$$\text{Total turning time for lands} = \frac{W^2}{2(2n-1)(c3)S_e\,w}$$

$$\text{PE for lands} = \frac{\dfrac{fW}{(c3)\,S_p\,w}}{\dfrac{fW}{(c3)\,S_p w} + \dfrac{W^2}{2(2n-1)(c3)\,S_e w} + \dfrac{(n-1)\,f}{(c3)\,S_p}}$$

Rearranging, the pattern efficiency (PE) for the lands becomes

$$PE = \frac{(4n-2)\,fW\,S_e}{(4n-2)\,fW\,S_e + W^2 S_p + (4n^2-6n+2)\,fwS_e} \tag{1.4}$$

The last term in the denominator of Eq. 1.4 may be omitted with an error of less than 2% for n = 5, but the error rises rapidly if n is greater than 10.

A plot of Eq. 1.4 for the example values is shown in Fig. 1.9 where length of the plowed land is f. The peak efficiency for this field of 12 ha [29.65 a] appears to be about 5 back furrows or 9 lands.

Rather than plotting a curve for each field situation, the optimum number of lands, as specified by the number of back furrows, can be expressed by Eq. 1.5. (See Appendix B.)

$$n = 0.5 + \sqrt{\frac{W^2 S_p}{4\,fw\,S_e}} \tag{1.5}$$

Using Eq. 1.5 on the example data in Fig. 1.9 gives the optimum number of back furrows as 5.24. Yet, because of the flatness of the curve near its peak,

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little loss in pattern efficiency exists with significant variation in the number of back-furrowed lands. Eq. 1.6 gives the range in back-furrowed lands for a permissible reduction in pattern efficiency.

$$n_{1,2} = \frac{W^2}{2w}\left(\frac{1}{Z} - 1\right) + 0.75 \pm \sqrt{\frac{W^2}{4w^2}\left(\frac{1}{Z} - 1\right)^2 + \frac{W}{4w}\left(\frac{1}{Z} - 1\right) - \frac{W^2 S_p}{4fwS_e} + 0.0625} \qquad (1.6)$$

where the new symbols are

$n_{1,2}$ = double answer defining the range
Z = acceptable field efficiency, less than the optimum

In the example data of Fig. 1.9, the pattern efficiency is optimum at n = 5.24 and is computed to be approximately 0.95. If a 2% drop in efficiency is acceptable, then Z = 0.93 and the range in the number of back-furrowed lands is 3.0–10 according to Eq. 1.6. For this example it is seen that the number of lands is not critical if the extreme values are avoided. Excessive wheel traffic on the soil in the headlands, especially near the ends of the back furrows, can be considered at this point. The upper end of the range should be used if soil compaction is troublesome.

An easier computation is for the optimum width of the lands, Eq. 1.7,

$$\text{opt. land width} = \sqrt{fwS_e / S_p} \qquad (1.7)$$

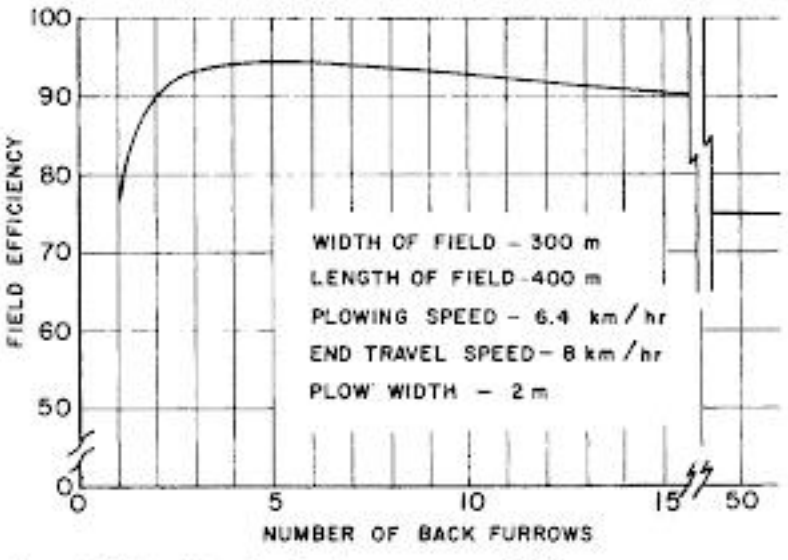


Fig. 1.9. Headland plowing pattern efficiency as function of number of lands.

For the data in Fig. 1.9, the optimum land width is found by Eq. 1.7 to be about 32 m. This width needs to be adjusted slightly to 33 m so that a whole number of lands, 9, will be scheduled. On the other hand, 32 m is exactly 16 trips by the plow. The best management scheme would have a whole number of plow trips in a whole number of lands.

One-way oriented implements other than moldboard plows, such as side-mounted cutterbar mowers and offset pull-type harvesters, can be modeled with some modification by Eq. 1.5 and 1.6. For harvesting implements there is no dead-furrow finishing time; but extra time (and crop damage) may occur as the lands are opened with the initial travel to break-through the standing crop. If one can equate the extra time to break-through to that gained by not requiring a finish trip, Eq. 1.5, 1.6, and 1.7 are applicable without modification. In such an instance, n is the number of break-throughs required.

Headland patterns are also used for self-propelled machines. The width of the lands is determined by the length of an easy turn on the headland and is shown in Fig.1.7 as an overlapping alternation pattern.

To enable comparisons of patterns, the time for plowing the headlands must be added to Eq. 1.4. The headlands are really 2 additional lands and are treated as back-furrowed lands with the average end travel equal to (1/2)(L –f)/2. Since the idle travel distance is small, the end travel speed might be slower than the assumed headland travel speed S_e

$$\text{Plowing time to finish headlands} = \frac{(L-f)W}{(c3)wS_p}$$

$$\text{Total time turning at headland ends} = \frac{(L-f)^2}{4(c3)wS_e}$$

Adding these two items to Eq. 1.4, the complete pattern efficiency, PE, becomes

$$PE = \frac{4(2n-2)LWS_p}{4(2n-1)LWS_p + 2W^2S_p + 4(2n^2-3n+1)fwS_e + (2n-1)(L-f)^2S_p} \qquad (1.8)$$

Circuitous Pattern, Diagonal Turn Strips

The circuitous pattern with diagonal turn strips is another popular pattern for plowing. For proper operation the turn strips must be exact bisectors of the

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square corners of the field. A strip equal to the width of the turn strips, s, is left in the center and is finished with the turn strips. It is assumed that turning speed, finishing speed, and plowing speed are equal.

The total plowing time for this pattern is computed by dividing the width of the plow, w, into the net area of the field to get a total furrow distance:

$$\text{land plowing time} = \left(\frac{LW}{w}\right)\frac{1}{(c3)S_p}$$

$$\text{total time lost in turns} = \frac{4s}{(c3)S_p}\left(\frac{W-s}{2w}\right)$$

$$\text{time to turn 6 turn strip ends} = 3\frac{s}{2}\left(\frac{s}{w}\right)\frac{1}{(c3)S_p}$$

$$\text{time to finish dead furrows} = \frac{4(1.414)W/2 + L - W}{(c3)S_p}$$

$$PE = \frac{LW}{LW + 2sW - s^2/2 + 1.828wW + wL} \qquad (1.9)$$

It is assumed that the turn strip, s, will be a whole multiple of w to avoid inefficient finishing travel. The time to lay out the diagonal turn strips is omitted. These turn strips should be marked off with a shallow furrow before starting to plow the field. Potentially, the time for this marking process is about the same as the dead-furrow finishing time.

Continuous Pattern

The efficiency of the continuous pattern depends greatly on quick turns at the headlands. E. S. Renoll (Auburn University) suggests that headlands should be smooth and wide enough to permit an easy turn in a few seconds. Narrow headlands will increase the turning time if the forward speed must be slowed to accomplish short turns, but they will require less time to process when field operations are being concluded. A headland of 2w width provides adequate room for high-speed turns yet limits finishing travel to two passes.

Wide maneuverable machines can usually make a pivot turn on a headland (Fig. 1.1). Unlike other vehicles, farm tractors and self-propelled implements have individual wheel brakes to assist in making sharp turns.

The time loss for a continuous pattern, using a two-way plow, involves only the turning time, t, at the headland. Since this turn requires little travel and may involve stopping and backing, the time loss is best expressed as seconds per turn. The headlands are finished in a continuous pattern also.

$$\text{Total time for turning} = \frac{t}{3600}\left(\frac{W}{w} + \frac{L-f}{w}\right)$$

$$\text{Total time for plowing} = \frac{LW}{w(c3)S_p}$$

$$PE = \frac{LW}{LW + (c3)tS_p(W + L - f)/3600} \qquad (1.10)$$

Notice that the pattern efficiency is not affected by the width of the plow, w.

Circuitous Pattern, Rounded Corners

The circuitous pattern would appear to have the greatest field efficiency as the operation is continuous (Fig. 1.10). However, an unprocessed, crescent-shaped area is left at each turn. Fig. 1.11 illustrates

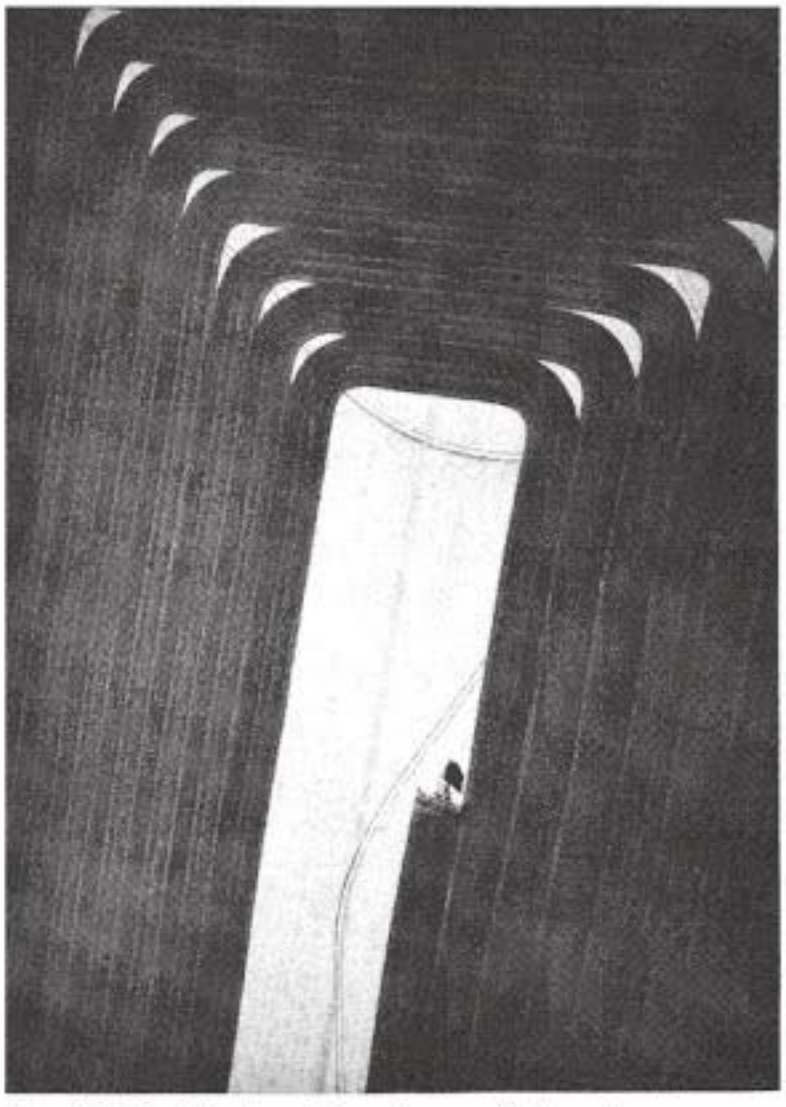


Fig. 1.10. Aerial view of continuous field pattern.

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0.414, an extra pass is required before continuing round 5 from this corner. Note that the extra passes must start their curvature a distance of 2.42w prior to the previous point where curvature commenced. The extra pass will overlap some portion of the previous round except at the center of the crescent where the full width of the implement will be utilized.

The time wasted in the circuitous rounded corner pattern will be considered to be only that lost in making the extra passes at the corners. If the implement is capable of a shorter turning radius when disengaged, as with a moldboard plow, the time for extra passes may be shortened. Fig. 1.12 indicates r_0 as a short turning radius with the implement disengaged.

Assuming the average speed of travel for the extra pass is S_p, the total time lost for $\pi/2$-rad [90°] corners equals

$$\left[\frac{270}{360}(2\pi r_0 + \frac{r + 2.42w - r_0}{0.707} + \frac{2\pi}{4}(r + 2.42w)\right]\frac{0.414\ W4}{2\ w\ (c3)\ S_p}$$

The pattern efficiency for the rounded corner pattern is approximated by Eq. 1.12:

$$PE = \frac{L}{L + 2.73\,r_0 + 4.48\,r + 6\,w} \qquad (1.12)$$

Obviously some additional time will be required to locate the position and length of the initial back furrow. While these times are not included in Eq. 1.13, adequate time spent initially will reduce the finishing time at the edges of the field. This pattern is a good plowing pattern to alternate with the circuitous types that throw soil away from the center of the field.

Table 1.2 compares the plowing pattern efficiencies for a square field of 16 ha [40 a] in area. Patterns that require the least turning time exhibit higher field efficiencies. The alternation pattern and the circuitous pattern with square corners are omitted as they do not apply to moldboard plowing. The continuous pattern can be realized for moldboard plowing with a two-way plow.

Tillage implements other than moldboard plows make good use of the continuous pattern if their turning radii are no greater than the effective width of the implement. Good use is also made of the rounded corner, circuitous pattern, as the extra pass problem occurring in plowing may be replaced with diagonal finishing trips. With these implements the efficiency for the rounded corner pattern can be greater than for plowing. The only wasted time is that spent finishing the diagonals where previously processed ground is reworked. (Fig. 1.11.)

Circuitous Pattern, $3\pi/2$-rad [270°] Turns

The circuitous pattern with $3\pi/2$-rad [270°] turns is usually started at the center of a land when plowing so that the turns will be on unplowed rather than plowed ground. As far as field efficiency is concerned it is immaterial where the operation commences if one assumes that turning on the plowed ground is as fast as on unplowed ground.

Fig. 1.13 shows the geometry of a $3\pi/2$-rad [270°] turn.

$$\text{Time for a turn} = \left[2r_0 - w + \frac{3}{4}(2\pi)\right]\frac{1}{(c3)S_p}$$

In this case S_p is the speed of the outermost part of the width of action. It should be realized that the average speed of the implement is less than S_p. The pattern efficiency for the $3\pi/2$-rad [270°] turn pattern is given by Eq. 1.13.

$$PE\frac{L}{L - 2w + 13.42r_0} \qquad (1.13)$$

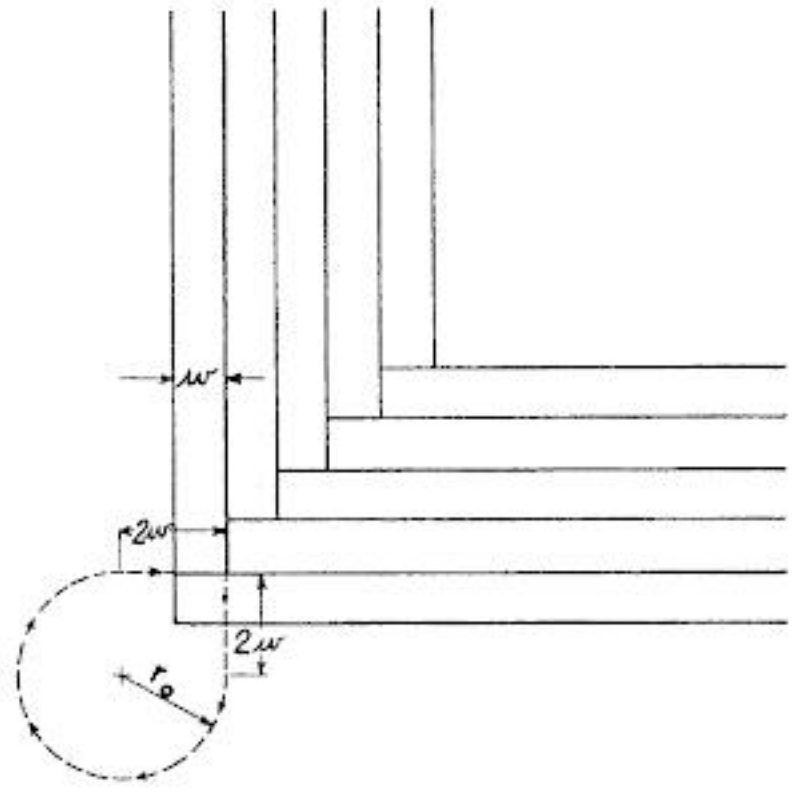


Fig. 1.13. Geometry of $3\pi/2$-rad [270°] turn; $r_0 = 2w$.

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TABLE 1.2. Plowing Pattern Comparisons, Square Fields

Pattern	Comments	Pattern Eff., %
Headlands	f = 394 m [1292 ft] 6 m [19.6 ft] headlands n = 5 (optimum) S_c = 8.0 km/hr [5 MPH]	93.0
Continuous	t = 10 s f = 394 m [1292 ft]	95.7
Circuitous,	s = 10 m [32.8 ft] diagonal turn strips	94.8
Circuitous, rounded corners	π/2-rad [90°] corners r_0 = 3 m [9.8 ft] r = 6 m [19.6 ft]	91.9
Circuitous,	r_0 = 6 m [19.6 ft] 3π/2-rad [270°] turns	84.0

Note: L = W = 400 m [1312 ft]; S_2 = 6.4 km/hr [4 MPH]; and w = 2 m [6.56 ft].

Row crops may be planted in any of the plowing patterns, but the continuous pattern is most used because of the need to supply the planter at the headlands and because the rows are commonly spaced from a boundary. If the rounded corner pattern is used for planting, the pattern efficiency is 100%, but the missed crescent-shaped areas will reduce the effective area of the field.

Both row crop cultivation and harvesting patterns are dependent on the prior planting pattern. The alternation patterns are possible only with tractor-mounted or self-propelled equipment and continuous or headlands planting patterns. The alternation pattern efficiency can surpass other types of headland patterns when the easier turn permitted by processing alternate sets of rows results in less time for turning.

When the yield of a field is large, consideration for the problems in harvesting should override planting pattern considerations. Ideally the harvesting pattern should be such that the first half of the travel is away from the field gate and the last half toward the gate. Thus each binful or wagon load is released at a point requiring the least field travel for transportation equipment.

One optimum harvesting pattern follows planting patterns that use a headland. If the size of the field and the crop yield are balanced, the harvester makes a whole number of rounds per unloading and always empties a full load on the headland nearest the gate. Such ideal conditions are rare.

For large fields, consideration should be given to dividing the fields into lands. For example, if corn is yielding 8 t/ha [127 bu/a], a 4-row corn combine with a 1.6-t [63-bu] grain tank is filled after only 500 m [1640 ft] of travel. Lands 250 m [820 ft] in length are needed. Fig. 1.14 illustrates the division of a field into lands of efficient length. The turn strips may be left open, planted to an early maturing crop, or planted to the main crop and harvested first. An alternative to dividing the fields into lands is to use larger wagons and/or use extension sides on the grain tank.

The circuitous pattern with diagonal turn strips should not be overlooked as a possible planting pattern for row crops because of its potential benefits for harvesting. After the diagonal turn strips are harvested the field is opened to effective use of transport equipment. The harvesting starts in the center of the field. The transport equipment is thus able to go to the center of the field and proceed directly to a meet with the harvester. Such a pattern eliminates traveling around the field to the far side to pick up a load, which is a 1 in 4 chance if harvesting starts from the boundary. Crops having high tonnage yields such as silage crops and sugar beets will profit most from this pattern.

For solidly planted crops such as small grains and hay crops, the circuitous pattern with square corners is worked from the outside in. The ability to keep the

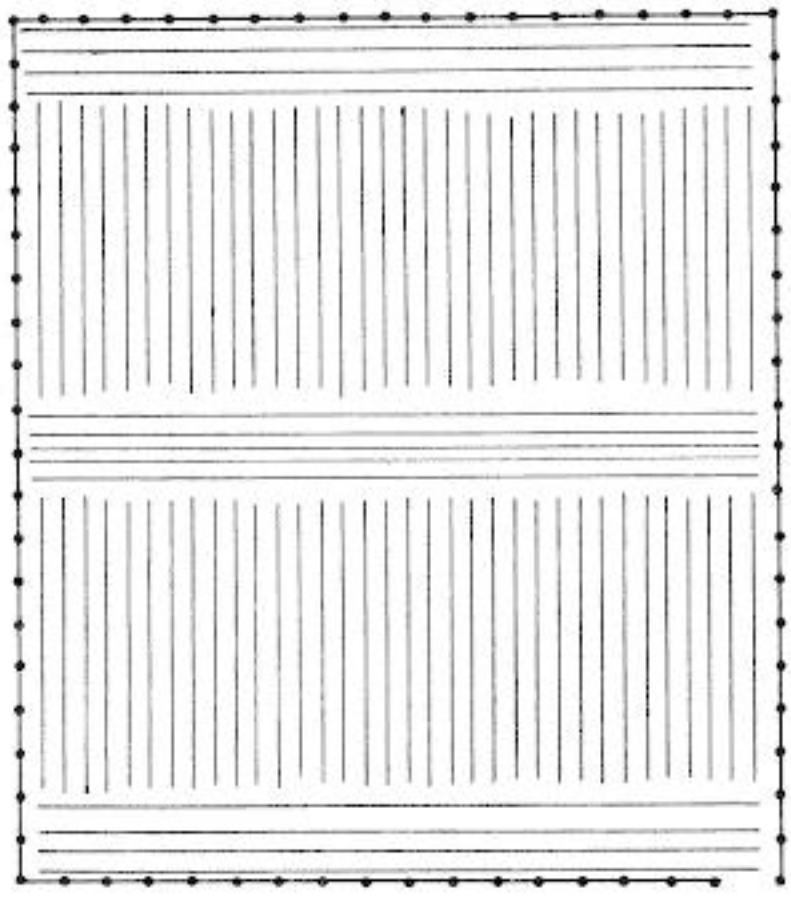


Fig. 1.14. Field divided by turn strip to improve harvesting pattern efficiency.

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corners square is of prime importance in keeping the pattern efficiency high; otherwise, the field will not finish out evenly and extra time will be spent in processing the odd-shaped areas remaining.

Field Shape

The field efficiency for irregularly shaped fields is expected to be significantly less than for rectangular fields because of excessive turning time. Even if the irregular fields are straight-sided the ratio of turning time to operating time will be high.

All the patterns illustrated in Fig. 1.7 are possible patterns for plowing irregular fields. The continuous pattern used with a two-way plow has the greatest efficiency for contour work and other irregular shapes. If the headlands pattern is used, the headlands should be selected to be as perpendicular to the back furrows as possible. The $3\pi/2$-rad [270°] circuitous type pattern is almost impossible to start from the center of an irregular field, but the pattern can be used if started from the boundaries. The actual degrees of turn will probably range widely on each side of $3\pi/2$-rad [270°].

Figure 1.15 indicates a combination of the turn strip and rounded corner patterns for moldboard plowing a very irregular field. This pattern follows principles listed here that were established by Leo Ahart (Dow City, Iowa) in 1922.

1. When corners are more than $\pi/2$-rad [90°], a rounded corner pattern is followed and maintained unless the corner angle sharpens to less than $\pi/2$-rad [90°], as in the lower right-hand corner of Fig. 1.15, whereupon a turn strip is established.
2. Uniform-width turn strips are marked off with a shallow plow furrow on each side of the bisector of the corner angles. In corners where the angles change rapidly, only short mark furrows are plowed at a time.
3. It is necessary to continue the pattern even when short furrows result, as indicated near the center of the field in Fig. 1.15. Subsequently, the turn strips may be plowed as lands with either back furrows or dead furrows. If the turn strips have been carefully laid out with a constant width, they will finish out evenly with little time loss.

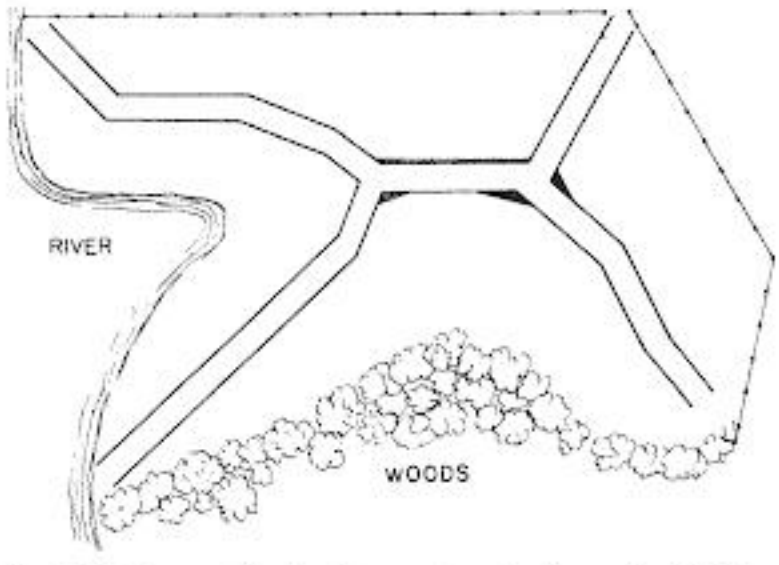


Fig. 1.15. Turn strip plowing pattern for irregular field.

Ahart sold a device to aid in accurately bisecting the angles. A small length of cardboard was held out at a distance determined by a taut string knotted through the cardboard and held in the teeth. The width of the angle was measured by the scale marked on the cardboard and the bisector determined by dividing the measured width by two. A prominent feature of the landscape was noted to indicate the direction of the bisector. The mark rows were then laid out about 4.5 m [15 ft] on each side of the bisector—all without leaving the tractor seat.

Long fields can improve pattern time efficiencies significantly. In a study of two-row cultivation, E. S. Renoll (Auburn University) found sizable differences in the proportion of turning time required for irregular fields with different row lengths:

	Field A	Field B
Range in row length, ft	400-165	1060-1000
Turning time, % total time	20	3
Field capacity, a/hr	1.9	2.9

The effective field capacity of the cultivator increased over 50% when operated on longer row lengths. Carried to a ridiculous extreme, the most efficient shape is the field only as wide as the implement; thus no time is lost in turning.

Fields of irregular shapes have inefficiencies related to headlands at an angle to machine travel (Fig. 1.16). A machine having a swath width, w, approaches the headland at angle A. To completely cover all the ground, the implement must cover all the cross-hatched areas too. In addition, the length of the turn is increased by w/tan A over that of the π-rad [180°] turn. This extra travel causes losses in time and effort—and seed and fertilizer in the case of seeding machines. In row crop production this loss is called *point-row loss*.

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The cross-hatched area is processed needlessly again when the headland is processed. The total area of this loss for a complete turn is $w^2/\tan A$. This relationship shows

1. The wasted area approaches zero as A approaches a right angle, but is extremely high if A is $\pi/6$-rad [30°] or less.
2. The loss varies as the square of machine width. The loss for a 4-row machine is 4 times as great, and the loss for an 8-row machine is 16 times as great, as that for a 2-row machine.

The total area of angled headland loss depends on the relative size of the implement to the field and on the field pattern. For example, a triangular 16-ha [40-a] field has a length of 800 m [2624 ft] and a width of 400 m [1312 ft], Fig. 1.17. Should the rows or swaths be parallel to side L, the total number of trips across the field would be W/w and the total wasted area would be the number of angled turns, W/(2w), times the wasted area per turn, $w^2/\tan A$. Eq. 1.14 shows the total area of wasted angled headland.

$$AHL = \frac{w\,W}{2\tan A} \qquad (1.14)$$

where AHL = area wasted because of angled headland, m^2 [ft^2]
w = width of machine, m [ft]
W = dimension of field perpendicular to machine travel, m [ft]
A = angle of headland (Fig. 1.16), rad [deg]
L = length of field, m [ft]

Substituting the field dimensions and a machine width of 4 m [13.12 ft] into Eq. 1.14 gives

$$\frac{4\times400}{2\times0.5} = 1600\,m^2\,[17{,}222 ft^2]\,\text{wasted area}$$

This loss, as a fraction of field area, is 1600/160,000 or 1%; that is, a 4-m machine working in this field will operate 1% more for every crop operation every year than in the same size field without angled headlands. Also, 1% of the seed, fertilizer, and chemicals applied to the field will be wasted every year.

In a more general case, angled headlands are found at both ends of a field as in Fig. 1.18 where the machine swaths are parallel to the hypotenuse. The wasted areas at each end equal $w^2/\tan A$, and the angles are arc tan (L/W) for one end and W/L for the other. The number of trips across the field will be approximately X/w where X is $W\,L/\sqrt{L^2+W^2}$. The number of turns at each end equals X/(2w); therefore, the total wasted area is $w\sqrt{L^2+W^2/2}$.

For the 16-ha [40-a] field and 4-m machine used previously, the total wasted area is

$$(4/2)\sqrt{800^2+400^2} = 1788 m^2\,[19{,}255 ft^2]$$

or 1.1% of the field.

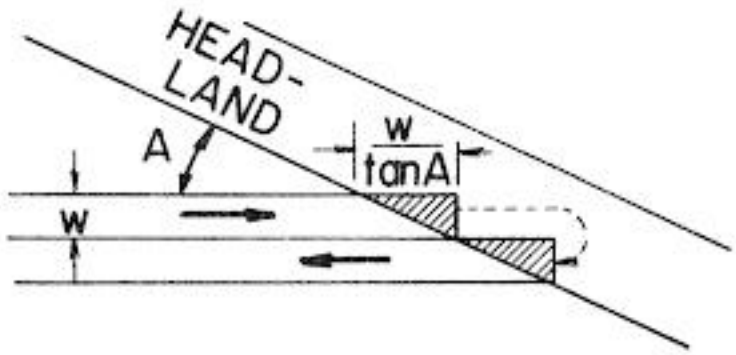


Fig. 1.16. Angled headland loss.

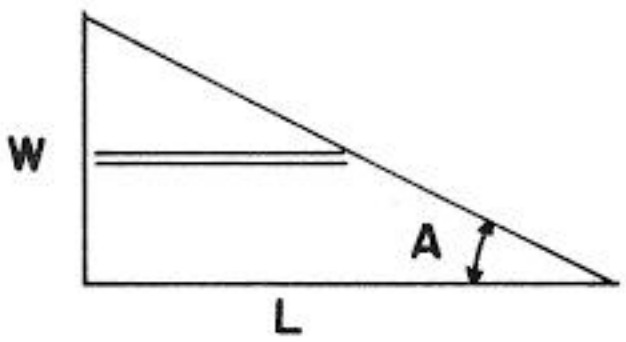


Fig. 1.17. Pattern parallel to perpendicular side.

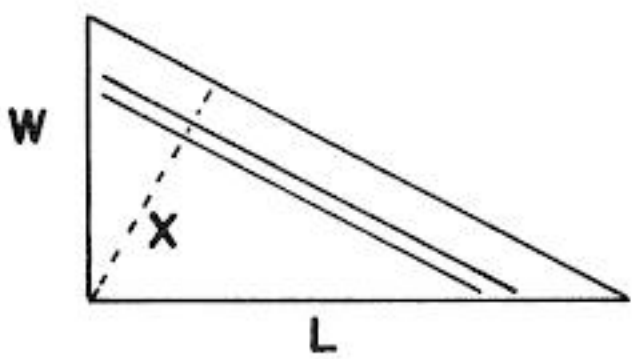


Fig. 1.18 Pattern parallel to angled side.

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grain in the tank from an area yielding 1 t. If only quantity is important this report of material efficiency is adequate; but if damaged grain or foreign matter in the tank reduces the value of the harvest, a quantity basis alone is not adequate to define material efficiency. Yet the quality of a harvested product depends only partially on how carefully it was handled by the machine. Furthermore, damaged products or contaminated products are not necessarily worthless. The most realistic measure of material efficiency must be the reduction in the value of a material after being handled by a machine compared to the value it would have with no material losses or deterioration.

Consider the material efficiency of a hay rake. The value of an area of hay before raking might be $10. After hay is windrowed the value might be $15. In some way it is determined that 50¢ worth of material was shattered onto the ground and that a perfectly raked windrow would not have had so many leaves exposed on the windrow surface resulting in a loss in vitamin A worth 30¢. The material efficiency would thus be $5.00/$5.80 or 86%. While this *economic concept* of material efficiency is difficult to apply, one should realize that such a concept is the only true measure of a machine's material efficiency.

Material efficiencies for tillage implements are impossible to calculate unless dollar values can be assigned to different physical conditions of the soil. Seeding machine material efficiencies depend on the value of the seed that is damaged and on the loss associated with not producing a perfect seeding pattern. Cultivator material efficiency must evaluate such intangibles as soil placement, weed kill, soil aeration, etc.

Performance Testing

The prospective user of farm machinery needs to have quantitative measures of the area and/or material capacities of a particular machine, as testing the machine before buying is usually impossible; consequently, the user must depend on the manufacturer's data or on results obtained by experiment stations or testing agencies. In Europe, government testing stations for farm implements are quite common. In the United States, it has been generally agreed that no one central agency could evaluate machine performance with any degree of significance because of the wide variation in crop and soil conditions. The situation would appear to be most unfavorable to the farmer; yet it is a consequence of the complexities of agriculture and is not a conspiracy against the consumer of farm machinery.

An example of a regional farm machinery testing program is that of the Prairie Agricultural Machinery Institute (PAMI) sponsored by the provinces of Saskatchewan and Manitoba in Canada. PAMI maintains a working relationship with the Alberta Farm Machinery Research Center (AFMRC) to provide machinery performance data to all three prairie provinces. Organized in 1974, the program's objectives were evaluation of existing agricultural machinery and development of new and improved machinery for prairie conditions. A typical evaluation report included a description of the machine; the scope of the tests conducted; results of the functional operation of the implement including capacity, ease and effects of adjustments and power requirements; and a history of mechanical and functional failures and changes required during the testing. The test could last for as long as 100 hours or 1000 ha. Safety for the operator and the adequacy of the operator's manual were also discussed in the report. Institute recommendations for changes in implement design and manufacture were followed by a response to the recommendations by the manufacturer.

PAMI work is helpful to machinery managers in predicting machine performance, fuel consumption and power required. The report for a test of a rectangular baler included photographs of sample bales from over 15,000 produced in baling four forage crops; a plot of both instantaneous and average power requirements (Fig. 1.22) and a mechanical history of the test (Table 1.4).

Recently, PAMI has de-emphasized machine evaluation in favor of research and development responses to machine-related items of interest to the many producer associations in Canada. PAMI now has seven major subject matter divisions: Energy and Processing, Soils and Crops, Hay and Forage, Livestock, Harvesting, Tractors, and Engineering and Testing Services.

PAMI information includes videos, books, and publications "Research Update" and "R&D Report." Considerable information is available from the internet site <www.pami.ca.> The mail address is P. O. Box 1050, Humboldt, Saskatchewan, S0K 2A0 Canada. An annual PAMI subscription entitles one to the Institute's publications. Current subscription fees are $20 for Canadian residents outside Manitoba and Saskatchewan and $25 Canadian for U.S. residents.

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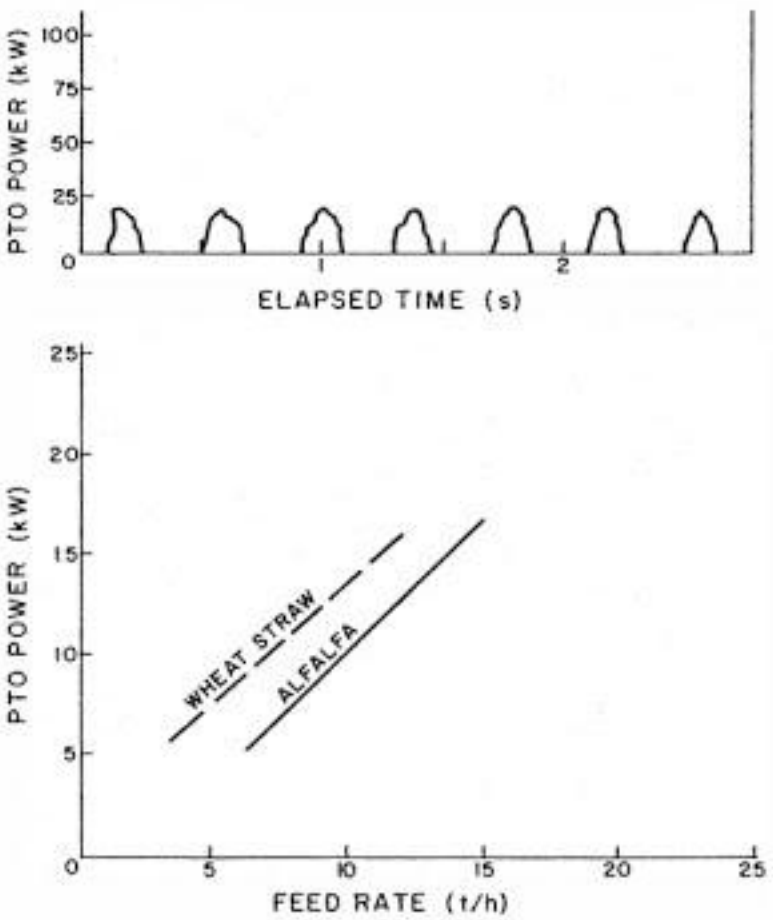


Fig. 1.22. Rectangular baler power measurements by PAMI.

results of machinery tests to specific farm situations. There are wide variations in crops and soils and some variations between individual machines of the same model. But intelligent use of test results such as those from PAMI help reduce the uncertainty facing machinery managers when they seek to select machines for field work.

The USDA National Tillage Machinery Laboratory at Auburn, Alabama, is a facility for research and performance testing of tillage implements, traction, and transport devices. Much of the work is done with an instrumented test car on rails that straddles large bins containing soils ranging from sand to predominately clay. Tests of full-sized tillage tooling (plows, disks, etc.) and of traction devices, such as the crawler tracks in Fig. 1.23, have influenced tractor and implement design since 1936.

TABLE 1.4. Mechanical History PAMI Test of Rectangular Baler

Item	Operating Hours	Equivalent Bales
Drive train		
Slip clutch began to slip excessively, readjusted to specifications at	58; 88	7,580; 11,900
Feeder assembly		
Feeder carriage roller-to-track clearance checked and adjusted to specifications at	60	8,840
Lost feeder carriage roller cap replaced at	91	12,660
Side play on feeder carriage became excessive; shims added to side wear blocks at	91	12,660
Plunger		
Bent plunger face extension straightened at	9	690
Broken plunger face extension replaced at	32	5,160
Plunger and knife-to-knife clearances checked and adjusted to specifications at	32	5,160
Twine needles		
Broken left twine needle replaced at	9	690
Bale chute		
Broken bale chute chain support bracket replaced at	101	15,460
Cracked bale chute frame at base of deflector arm repaired at	101	15,460

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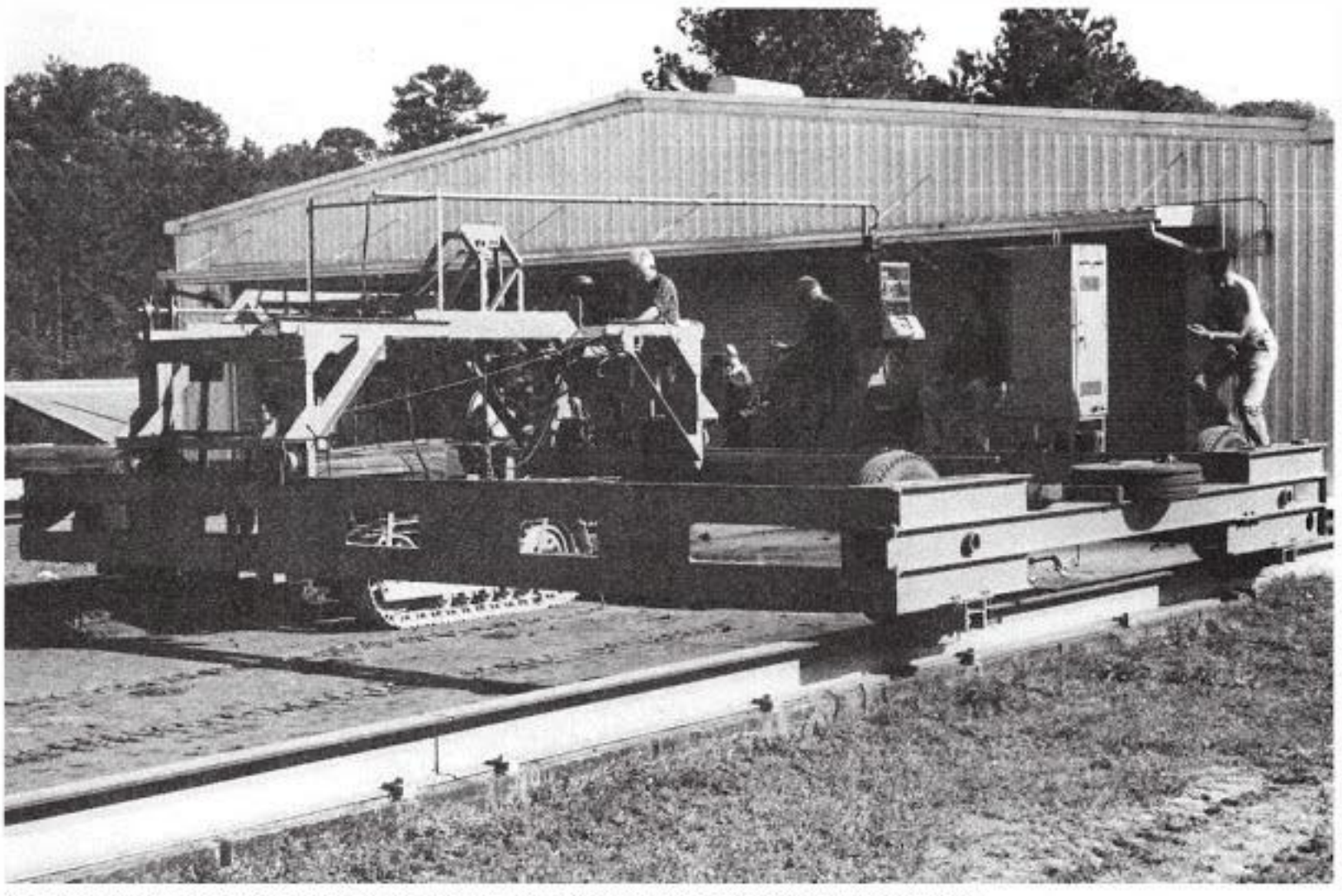


Fig. 1.23. Analyzing tractive effort at the USDA National Tillage Machinery Laboratory.

Practice Problems

1.1. Find the theoretical machine capacity in hectares per hour [acres per hour] using the unit factor system described in Laboratory Exercise 1 for a 3-m [9.8-ft] width-of-cut mower observed to travel 100 m [328 ft] in 52 s.

1.2. Show that the constant in the equation for theoretical capacity in acres per hour for metric machines is really 4.047 instead of 4.

1.3. A 5-m [16.4-ft] width-of-cut self-propelled combine makes an average stop of 4 min every time its 2-t [73.3-bu] grain tank is to be unloaded. This stop includes the time for adjustments, lubrication, refueling, and the operator's personal time. The gross yield of the field is 2.1 t/ha [31.17 bu/a]. Material losses are measured as 0.1 t/ha [1.48 bu/a]. The operating speed is 4.8 km/hr [2.98 MPH]. The time for turning on a headland at the ends of the 400-m [1312-ft] field is 15 s. The average actual width of cut is 0.95 of theoretical. Find

a. Theoretical field capacity

b. Effective or actual field capacity

c. Field efficiency

d. Percentage of time loss

e. Material efficiency

1.4. Enter Eq. 1.3 into a programmable calculator or computer for easy and rapid repetitive solutions. Find the most sensitive variable in the equation by determining the largest percentage increase in the effective field capacity upon entering in

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turn a 20% improvement (increase or decrease in value) for S, w, L, E_w, D, t, and size of grain tank. Use data in problem 1.3 as base values.

1.5. Self-propelled windrowers are capable of reversing their drive wheels independently while their rear wheels swivel. What would be an optimum dimension for the horizontal distance between the cutter bar and the drive axle to permit a perfectly square turn? Express the answer in terms of cutter bar width, w. Would any of the standing grain be backed over by any part of the windrower during this turn?

1.6. A pulled PTO-driven 3-row harvester is used in a row crop planted in 500-mm [19.68-in.] rows. The field is 400 m [1312 ft] long and was planted with 12-row headlands to enable the end turning speeds to equal the field speed of 6.5 km/hr [4 MPH].

a. What is the width of the optimum land for this operation? (Express in terms of the number of implement trips.)

b. If the field is 300 m [984 ft] wide, how many times will it be necessary to break through the field to establish a new land?

c. What is the maximum yield that would just fill a wagon of 4-t [4.4-T] capacity in one trip across the field?

1.7. A round baler spends about 1 min total in stopping forward motion, backing away from the windrow, wrapping the bale with twine, and restarting baling. Assuming a throughput of 9 t/hr [10 T/hr] in a field yielding 2.25 t/ha [1.0 T/a], determine the field efficiency. The windrows have been made from two 3-m [10-ft] swaths and are laid in a circuitous pattern. Neglect any downtime stops. An individual bale weighs 450 kg [1000 lb]. What forward speed is necessary to achieve the throughput capacity?

1.8. The fertilizer hoppers on a planter will hold 90 kg [198 lb] for each row. The required fertilization rate is 340 kg/ha [303 lb/a]. Row spacing is 1 m [39.4 in.] and the length of the field is 800 m [2625 ft]. Under such conditions, 54.4 kg [120 lb] would have to be added to each hopper at the end of each round. Less time would be wasted if a procedure could be arranged that would allow the fertilizer hoppers to empty further before refilling. Evaluate the following proposals.

a. Go $1\frac{1}{2}$ rounds with fertilizer stored at each end of the field.

b. Add extensions to the hoppers to allow 2 complete rounds.

c. Divide the field into lands with row lengths one-fourth the original and place fertilizer supplies at each end of the new lands.

d. Buy more–concentrated fertilizer.

e. Place the fertilizer supply in the middle of the field only.

1.9. Sketch the shape of the cycle diagrams for machine systems made up of

a. One forage harvester, 1 forage blower, and 1 truck

b. One SP baler with bale thrower, 3 wagons, 2 tractors, and an auxiliary engine-driven bale elevator

c. Two SP combines, 3 trucks holding 4 dumps each, 1 grain elevator (show just one transportation loop; indicate others)

1.10. In Fig. 1.19 what unloading time would cause the unloader performance to just match the potential transport performance? What would be the new T_c?

1.11. Suppose Fig. 1.20 is a silage harvesting system. Find the system capacity if the loads carried by the wagons could be increased by 50% and 2 unloaders were used. With the exception of loading and unloading times the other data remain the same.?

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Chapter 2

POWER PERFORMANCE



A second measure of a machine's economic performance is the effectiveness with which power is applied to accomplish the farm's production objectives. A thorough understanding of the nature of power and its optimum use is essential to good machinery management.

American farmers have purchased many tractors to power their machines. The ratio of the number of people engaged in agriculture to the number of tractors on farms was 11 to 1 in 1930, 2 to 1 in 1950, and approximately 1 to 1 in 1975. In 1990 there were approximately two tractors available for every farm worker in North America.

Tractor power on farms will continue to be an absolute necessity for agricultural production. The total number of workers engaged in farming has dropped to less than 2% of the nation's population, yet total farm production continues to rise. Smaller numbers of tractors and self-propelled implements with greater power ratings will be used in the future if the production from a single farm worker is to continue to increase.

Power is defined as the rate of doing *work*. Work in a technical sense is the application of a force through a distance. The units for mechanical work are force × distance. Power then is work per unit time.

The problem of power units first arose in England with the development of the steam engine. In the latter portion of the eighteenth century, James Watt wished to rate his steam engines in terms of the competition—the horse. He ran a series of tests with average horses and found that a horse could lift 366 lb of coal out of a mine at the rate of 1 ft/s. In other units this was 22,000 ft · lb/min. Watt arbitrarily

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The linear speed of the belt (distance/time) is $2\pi R \times 2.5$ rev/s or 4 m/s. Using the linear power form,

$$\text{power} = \frac{\text{force} \times \text{distance}}{\text{time}} = \frac{1004}{1} = 0.4 \text{ kW}$$

Fluid power is defined as the product of a weight rate of flow and the resistance to that flow called the *head* of the fluid. Head describes the height of a column of fluid whose mass creates at the bottom of the column a pressure equivalent to that in the flowing system. In general terms,

$$\text{power} = \frac{\text{weight of fluid (force)} \times \text{head (distance)}}{\text{time}}$$

For example, if water weighing 10 kg [22.05 lb] must be pumped up a 100-m [328-ft] hill (through a frictionless pipe) in 10 s, the power required would be, in SI units,

$$\underline{0.98 \text{ kW}} = \frac{10 \text{ kg}}{10 \text{ s}} \times 100 \text{ m} \times \frac{1 \text{ W} \cdot \text{s}}{1 \text{ N} \cdot \text{m}} \times \frac{1 \text{ kW}}{1000 \text{ W}} \times \frac{9.8 \text{ N}}{1 \text{ kg}}$$

In customary units,

$$\left[1.31 \text{HP} = \frac{22.05 \text{ lb}}{10 \text{ s}} \times 328 \text{ ft} \times \frac{1 \text{HP} \cdot \text{s}}{550 \text{ ft} \cdot \text{lb}}\right]$$

The pressure of the fluid and not its head is used in most machinery management calculations. The preferred units of pressure are pounds per square inch (psi) in customary units and pascals (Pa) in SI units. A pascal is the pressure of one newton of force over an area of one square metre. Since a pascal is a very small unit, the kilopascal (kPa) is commonly used. The kilopascal is also small, being equivalent to 0.145 psi. The bar, 100,000 Pa or 100 kPa, is sometimes used as a convenient unit of pressure as it is numerically close to one atmosphere of pressure.

Tractor Power

Tractors deliver power in several ways. Pulled or towed implements are powered through the traction of drive wheels and the pull or draft from the drawbar. Rotary power is obtained from the power take-off (PTO) shaft or from a belt pulley. Both linear and rotary power can be produced by a tractor's hydraulic system. Some implements require electric power from tractors.

The tractor power equations (2.1, 2.2, 2.3, and 2.4) are convenient formulas with the necessary unit factor conversions included in the numerical constants.

Drawbar Power (DBP)

$$\text{DBP} = \frac{\text{FS}}{\text{c}} \tag{2.1}$$

where DBP = drawbar power expressed in kW [HP]
F = force measured in kN [lb]
S = forward speed, km/hr [miles/hr or MPH]
c = constant, 3.6 [375]

PTO Power (PTOP)

$$\text{PTOP} = \frac{2\pi \text{ FRN}}{\text{c}} = \frac{2\pi \text{ TN}}{\text{c}} \tag{2.2}$$

where PTOP = PTO power expressed in kW [HP]
F = tangential force, kN [lb]
R = radius of force rotation, m [ft]
N = revolutions per minute (rpm)
T = torque, kN·m [lb·ft]
c = constant, 60 [33,000]

Hydraulic Power (HyP)

$$\text{HyP} = \frac{\text{pQ}}{\text{c}} \tag{2.3}$$

where HyP = hydraulic power, kW [HP]
p = gage pressure, kPa [psi]
Q = flow rate, L/s [gal/min]
c = constant, 1000 [1714]

(Equation 2.3 applies to gaseous and air flows as well as liquid flows. Note that the density of the fluid need not be known.)

Electric Power (EP)

$$\text{EP} = \text{I E} \tag{2.4}$$

where EP = electric power, W
I = electron flow rate in amperes, A
E = electric pressure in volts, V (DC)

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Rolling Resistance

The operation of equipment over typical farm ground involves concepts of rolling resistance and weight components. Rolling resistance is the force required to keep the equipment moving at a constant speed and is proportional to equipment weight. This force is needed to provide the energy required to deflect rubber tires, to compress or push aside soft soil, and to overcome wheel- and axle-bearing friction. The term *coefficient of rolling resistance* is defined as the ratio of the horizontal force (draft) required to pull a loaded wheel over a horizontal surface to the vertical force on that wheel's axle. In customary units this ratio is pull/weight. In the SI system the mass of the load on the wheel must first be converted to force units by multiplying by g, the acceleration of gravity (9.807 m/s^2).

When equipment operates on a slope, the weight no longer acts perpendicularly to the slope through the wheels and axles but vertically at an angle equal to the angle of the slope. Rolling resistance is reduced because the weight on the wheels is reduced.

Slope is defined in this presentation as the tangent of the angle between the soil surface and the horizontal, expressed as a percentage.

Example

A tractor is pulling a 5000-kg [11,000-lb] loaded wagon up a 10% slope at 10 km/hr [6.2 MPH]. The tractor's mass is 3000 kg [6600 lb].

A. Find DBP if the coefficient of rolling resistance is 0.05 for all wheels. Refer to Fig. 2.3 and enter values found.

1. Angle a = arc tan 0.1 = 0.1 rad [5.71°]

2. Components of weight
   a. Perpendicular to the slope
      wagon: $5000 \times 9.807 \cos 0.1 = 48.790$ kN
      [11,000 cos 5.71° = 10,945 lb]
      tractor: $3000 \times 9.807 \cos 0.1 = 29.274$ kN
      [6600 cos 5.71° = 6567 lb]
   b. Parallel to the slope
      wagon: $5000 \times 9.807 \sin 0.1 = 4.895$ kN
      [11,000 sin 5.71°= 1094.43 lb]
      tractor: $3000 \times 9.807 \sin 0.1 = 2.937$ kN
      [6600 sin 5.71° = 656.7 lb]
   c. Fill in values in the proper blanks in Fig. 2.3.

3. Rolling resistance
   wagon: $0.05 \times 48.79 = 2.4395$ kN
   [$0.05 \times 10{,}945 = 547.25$ lb]

4. Drawbar pull
   2.4395 + 4.895 = 7.3345 kN
   [547.25 + 1094.43 = 1641.68 lb]

5. DBP = 7.3345 kN × 10/3.6 = 20.37 kW
   [1641.68 × 6.2/375 = 27.14 HP]

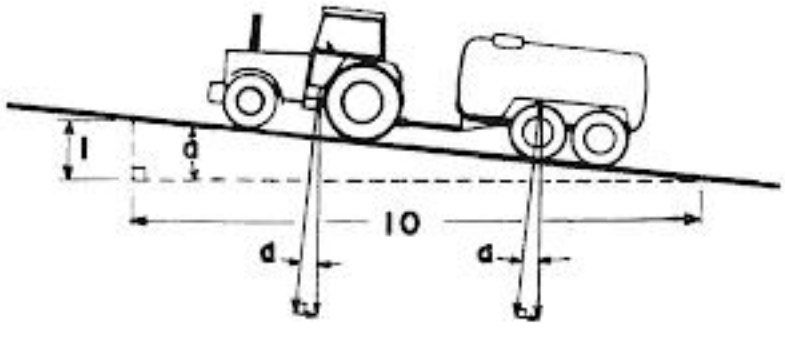


Fig. 2.3. Effects of weight on equipment moving up slope.

B. What is the additional power required to move only the tractor up the slope as compared to level ground? Use the data from the folling resistance example and from Fig. 2.3.

1. For flat surface
   a. Rolling resistance:
      $0.05 \times 3000 \times 9.807 = 1.471$ kN
      [$0.05 \times 6600 = 330$ lb]
   b. Po:··.: $1.471 \times 10/36 = 4.085$ kW
      [$330 \times 6.2/375 = 5.456$ HP]

2. For slope
   a. Rolling resistance:
      $0.05 \times 29.274 = 1.464$ kN
      [0.05×6567 lb = 328.35 lb]
   b. Downhill component of weight: 2.937 kN
      [656.7 lb]
   c. Power:
      $(1.464 + 2.937) \times 10/3.6 = 12.225$ kW
      [$(328.35 + 656.7) \times 6.2/375 = 16.29$ HP]

Increase is 8.14 kW [10.834 HP].

Power Measurement

Power is sometimes defined as energy in motion and as such is invisible. Special apparatus is required to determine the power output from an engine or a

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tractor. The following sections describe some of the apparatus and the common tests used in power measurement.

Engine Power Definitions

The power output of an engine is a function of the average pressure on the piston head and the engine speed. The average pressure acting during the power stroke of the engine is referred to as the mean effective pressure. *Indicated power* (IP) is the theoretical power an engine should develop from the mean effective pressure existing at the piston head. *Brake power* (BP) is the engine horsepower measured at the flywheel. The numerical difference between IP and BP is the power absorbed by the engine in overcoming friction to run itself (FP).

Engine Testing

Engine testing is accomplished with a dynamometer. The dynamometer may be a *transmission dynamometer* or an *absorption dynamometer*. Most engine tests are conducted with an absorption dynamometer—that is, the dynamometer has within itself the ability to load the engine.

A Prony brake is a simple form of absorption dynamometer that is easily understood. The engine is attached to a large flywheel equipped with an adjustable brake band. The brake band is restrained from turning with the flywheel by a platform scales as shown in Fig. 2.4. Eq. 2.2 may be applied directly to this type of dynamometer, where

F = force read on the scale
R = radius of scale arm
N = rpm

Note that for any one dynamometer all factors in Eq. 2.2 remain constant except F and N. The remaining factors may be combined to form a dynamometer constant, k:

$$k = \frac{2\pi R}{c}$$

A simpler power formula may now be written:

$$BP = kFN \qquad (2.5)$$

The Prony brake has many disadvantages; an electric or hydraulic dynamometer is a more satisfactory unit.

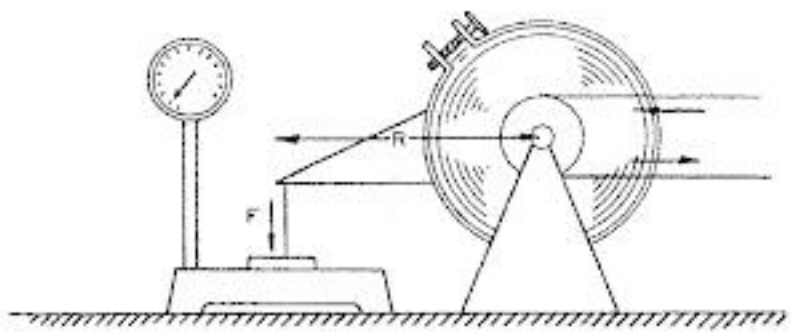


Fig. 2.4. Belt-driven Prony brake dynamometer.

The electric dynamometer may be just a generator. It may be cradle-mounted on bearings or stationary. The armature is connected across a heavy resistance load. The resistance to rotation of the shaft is provided by the electromagnetic forces between the armature and the field coils. The energy is dissipated in the form of heat at the resistance load.

Power may be measured by reading the current output of the armature circuit. In this case the generator characteristics of the dynamometer must be known. When cradled, the reaction force to producing power is measured at the end of the scale arm. In either case the load on the engine is varied by a rheostat placed in the field circuit of the generator.

An eddy-current dynamometer is another type of electric dynamometer that dissipates energy in the form of heat directly into cooling water. The reaction to this dissipation produces the force F contained in Eq. 2.5.

Hydraulic dynamometers are closed-circuit fluid systems that contain a pump, a variable relief valve, and a reservoir. The engine drives the pump and load is applied by closing the relief valve. Either the reaction force is measured or the pressure on the discharge side of the pump is used to estimate the reaction force.

The fuel consumption of an engine, often determined along with power measurement, can be determined in several different ways. One is by measuring the rate at which the fuel is flowing to the engine by some type of flowmeter. Another is by measuring out a volume of fuel and recording the time required to consume this quantity. A third method is to use a measured mass of fuel in the above procedure. In agriculture, fuel consumption is reported on an hourly basis.

Engine fuel efficiency is a ratio of fuel consumption to power output. At least four different efficiencies are computed. The most common and simplest is kW·hr/L [HP·hr/gal]. If different fuels are compared, a kg/(kW·hr) [lb/(HP·hr)] efficiency is most useful.

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Tractor Tests

The power performance of tractors is the most important information item needed by the farm machinery manager. The tractor is the base of the machinery system. It is often the most used machine on the farm and is frequently the most expensive. Economic farm management requires a careful matching of tractor capability to the farm's power needs. Reliable unbiased performance data, based on tests of sample models, is fundamental to good farm machinery management.

The need for reliable performance data arose in the early days of tractor manufacturing. In 1919, W. F. Crozier, a farmer as well as a legislator, introduced mandatory tractor test legislation in the Nebraska House of Representatives to provide farmers with unbiased information about tractor performance. The bill passed and the Nebraska Tractor Test Board was created and given the authority to require tractors offered for sale in Nebraska to be tested before being issued a sales permit. The University of Nebraska in Lincoln was selected as the testing agency. In addition to facilities for PTO testing, an oval concrete track is used for drawbar tests. While the law applied only to Nebraska sales, the industry accepted the results worldwide.

The test procedures have evolved over the years to accommodate changes in tractor technology. The test standards were codified by the American Society of Agricultural Engineers (ASAE) in 1937. A joint standard was issued by the ASAE and the Society of Automotive Engineers (SAE) in 1964. Past tests have helped evaluate such innovations as dual drive wheels, turbochargers, radial tires, new transmissions, and the efficiencies of various fuels.

As tractor manufacturers developed worldwide markets, a need arose for an international tractor test procedure to avoid redundant tests in each national market. The Organization for Economic Cooperation and Development (OECD) approved internationally recognized tractor testing procedures and named the Farm and Industrial Equipment Institute (later renamed the Equipment Manufacturers Institute [EMI]) as a "Designated Authority" for OECD testing. In 1986, the Nebraska Legislature voted to accept the results of either the SAE/ASAE or OECD tractor tests. In 1988, the Nebraska test facility began OECD tests, as well as their traditional ones, in the new role as an approved OECD testing station. OECD testing is global. Fig 2.8 reports results from a test conducted in Italy.

Kenneth Von Bargen, Department of Agricultural Engineering, University of Nebraska-Lincoln, reviewed the provisions for OECD testing at the 1988 Winter Meeting of the ASAE. Five different tractor test codes were listed.

Code I	Standard or full test performance code which consists of PTO, drawbar, hydraulic power, 3-point linkage lift, center of gravity, braking, and sound level tests.
Code II	Restricted standard performance code which has the same PTO test but drawbar tests are conducted without ballast.
Code III	A dynamic protective structure test.
Code IV	A static protective structure test.
Code V	A noise measurement test.

Different testing options are available to meet the requirements of different countries in which the tractor model will be marketed and to meet the marketing needs of the manufacturers. An official test report must provide the basic power and fuel performance characteristics of the tractor, the sound levels, and the 3-point hitch lift capability. The official test results must equal or exceed the manufacturer's claims or representations for power, fuel consumption, and sound levels.

Preparation for Testing

The manufacturer selects the tractor to be tested and certifies that it is a stock model. Each tractor is equipped with the common power-consuming units such as power steering, hydraulics, alternator, etc. An official representative of the company is usually present during the test to see that the tractor gives its optimum performance. Additional weight may be added to the tractor as ballast if desired. The static tire loads and inflation pressures must conform to the limitation established by the Tire and Rim Association. (See Table 2.1).

The engine crankcase is drained and refilled with new oil conforming to the specifications in the manufacturer's operator's manual. This manual is also used as a guide in selecting the proper fuel and for routine lubrication and maintenance.

The tractor is operated for several hours prior to testing to provide a representative test after the pistons and bearings "wear-in." Adjustment of the tractor is permitted at this time. Instrumentation for measuring

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engine rpm, fan speed, temperatures and pressures, and fuel consumption are installed.

PTO Performance

Engine power performance is tested by connecting a dynamometer to the tractor's PTO shaft. During a preliminary run the manufacturer's representative may make adjustment for injection pump volume and timing. These settings must be maintained for the remaining tests. The manually operated governor control is set to provide the high-idle (no-load) engine speed specified by the manufacturer. During the PTO runs an ambient air temperature of approximately 24°C [75°F] is maintained and the barometer reading should be above 96.6 kPa [28.5 in. Hg].

Power is measured at the rated engine speed specified by the manufacturer. Maximum power may be obtained at other than rated speed and is conducted for 2 hours. When the PTO speed for these test differ from the ASAE and SAE standards, an additional run is made at either the 540 or 1000 rpm standard.

The Varying Power and Fuel Consumption test provides a machinery manager with data on fuel efficiencies at part loads. These tests record the fuel consumption and power developed during six test loadings decreasing from maximum to no load.

Drawbar Performance

Drawbar pull tests are performed in all transmission gears between one gear below the one at which 15% drive wheel slip occurs and that for a maximum speed of 16.1 km/hr [10 MPH]. In each test the governor control is set for maximum speed (high idle) and the horizontal drawbar load increased until the maximum drawbar power is obtained. Measurements are taken of pull, speed, power, slip, fuel consumption, and sound. Sound level readings, db(A), are obtained with a microphone located near the right ear of the tractor operator. A bystander sound reading is taken with a microphone placed 7.5 m [25 ft] from the centerline of the tractor which is accelerating from a lower speed to full speed in its top gear. For tractors with mechanical front-wheel drive (MFWD), the operator ear measurements are made with the front-wheel drive both engaged and disengaged.

A second set of tests investigates part load performance. Drawbar loads of 75% and 50 % of the load at rated engine speed are applied in a gear close to 7.5 km/hr [4.6 MPH] and in the gear where maximum drawbar power was obtained in the previous tests.

Additional tests may be conducted. The manufacturer may wish a test at reduced engine speed, ballast-aided performance, performance with and without MFWD, and alternate tire configurations.

The procedures specify that distribution and total tractor weight will be in accordance with limits set by the tractor manufacturer, tire manufacturer, and roll-over protection certification. The weight shall include full fuel tanks and an 80-kg [175-lb] operator. Front end ballast can only be provided by a standard weight package and/or front tire ballast supplied or recommended by the manufacturer.

Three-Point Hitch Test

The tractor is tested on the same rear tires used during the drawbar tests. The front tires of two-wheel drive and front-wheel drive assist tractors may be of any size or ply offered by the tractor manufacturer as long as they properly match the rear tires. A quick-attaching coupler is used on all Category III and IV hitches and on any tractors on which it is offered as standard equipment; but the quick coupler is *not* considered part of the load lifted by the hitch.

Hydraulic Lift Capacity and Flow

The hydraulic lift capacity is measured in a special test stand. A frame is fitted to the three-point hitch links and measurements of lift capacity are taken at the hitch points and 61 cm[24 in.] behind the lower, horizontal hitch links. The load is generally applied with a hydraulic cylinder and the links move step-wise through the lift range. The number that is reported is 90% of the load which can be carried throughout the lift range.

A second test determines the pressure/flow relationship and performance of the hydraulic system for supplying power to external cylinders and motors. Measurements reported are pump flow rates at minimum pressure at rated engine speed and the pressure and flow at maximum hydraulic power .

OECD reports are available from the Tractor Test Laboratory, P. O. Box 830832, Lincoln NE 68583.

Some interpretation of the OECD tests is required for farm machinery management use. The PTO performance data can be used directly as indicative of the maximum useful power of the tractor (approximately 90% engine power). Variations from these values would be expected if operating air

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temperatures and pressures were different from those for the test. Weather combinations of low pressure and high temperature or high pressure and low temperature could cause as much as an 8% power decrease or increase, respectively. Decreases in air pressure with altitude can cause power losses of approximately 3%/300 m [1000 ft] altitude. The decreases are even greater at altitudes above a mile.

The drawbar performance data are not so readily applicable to farm machinery management. The tests for rubber-tired tractors are conducted on a concrete track and include only horizontal pulls. Neither condition is representative of the field tractor with integral equipment. The justification for such a procedure is that a standard test is accomplished permitting fair comparisons of different models of tractors.

Examination of the example OECD tests, Fig.2.8, 2.9, and 2.10 can lead to many comparisons of value to a machinery manager. The test data do lead to comparisons of different tractors; but, they also can indicate the effects of management decisions about different configurations of the same model tractor and about operational adjustments.

Fig. 2.9 allows a judgment of the increased performance from MFWD as the report shows performances with the MFWD engaged and disengaged. Engaging the MFWD in 5th gear increased the maximum drawbar power 7% from 25.91 to 27.73 kW [34.75 to 37.19 HP]. The drawbar pull remained essentially the same, but the % slip dropped from 14.84 to 8.49. Comparisons at just one test gear can mislead. Making the same comparison as above in 6th gear shows that engaging the MFWD provides minimal increase in maximum drawbar power, 27.27 to 27.39 kW [36.57 to 36.73 HP], 2.7% reduction in wheel slip, 7.80 to 5.09, and an actual decrease in drawbar pull, 9.12 to 8.85 kN [2051 to 1990 lb]. Keep in mind that these tests are on a concrete surface and are not always indicative of performances on soils.

Fig. 2.9 (including the supplement) also allows a judgment about engine turbochargers. Adding a turbocharger increased the power by an average of 13% and improved fuel efficiency by an average of 8%. (Note the name change of the manufacturer between the two tests.)

Fig. 2.10 indicates the effect of adding ballast and the benefits from reduced engine speed. Comparing maximum drawbar powers in 9th gear at 2200 rpm, adding 982 kg [2165 lb] of ballast to the front of the tractor produced a 2.9% increase in drawbar power, 145.97 to 150.2 kW [195.75 to 201.43 HP]; a 2% increase in drawbar pull, 70.84 to 72.73 kN [15925 to 16238 lb]; and a 29% reduction in slip, 3.28 to 2.34 %. The relatively small increase in power occurs because adding ballast consumes power as more weight has to be moved over the ground. This tractor's engine characteristics give greater performance at an engine speed of 2000 rpm. Comparing the ballasted tests in ninth gear, tested power increased 11.3%, 150.20 to 167.20 kW [201.43 to 224.21 HP], and fuel efficiency increased 6.5%, 3.06 to 3.26 kW·hr/L [15.55 to 16.57 HP·hr/gal].

The ability of a tractor engine to accept an overload is important in most field operations. Listed below the Varying Power and Fuel Consumption test in the Summary reports is a report of engine torque characteristics. The data in Fig. 2.8 reports that the maximum engine torque is developed at 1249 rpm, well below the rated engine speed of 2350. This maximum torque was 25% greater than at rated speed, 179.2 N·m [132 lb·ft]. An additional torque rise percentage is reported at an engine speed intermediate between maximum power and maximum torque. The industry often refers to this engine characteristic as its lugging ability.

Performance of tractors tested on concrete can be estimated for soil surfaces by curves shown in Fig. 2.11. Compiled by Frank M. Zoz (John Deere Waterloo Tractor Works), this chart considers the effects of engine power, ground speed, rolling resistance, ballast or added weight, and the type of implement hitch on the dynamic weight shift from the front axle to the rear. It predicts drawbar pull, drive-wheel slippage, and actual forward speed for three soil surface conditions and for concrete. It is limited to rear-axle-drive tractors with single-drive tires. It assumes proper ballast distribution to ensure adequate steering control at all times. Approximately 25%, 30%, and 35% of the total tractor mass is required on the front wheels for towed, semimounted, and mounted implements, respectively. The ratio of drawbar height to wheelbase is R. Slippage is defined as

$$\frac{\text{advance under no load} - \text{advance under load}}{\text{advance under no load}}$$

for a specified number of drive-wheel revolutions. Ten revolutions of the drive wheel is a common base for measuring the advance.

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Figure 2.8.

SUMMARY OF OECD TEST 1610—NEBRASKA SUMMARY 217
WHITE 6045 DIESEL
16 SPEED

POWER TAKE-OFF PERFORMANCE

Power HP (kW)	Crank shaft speed rpm	Gal/hr (l/h)	lb/hp.hr (kg/kW.h)	Hp.hr/gal (kW.h/l)	Mean Atmospheric Conditions
MAXIMUM POWER AND FUEL CONSUMPTION					
Rated Engine Speed (PTO speed—612 rpm)					
45.7 (34.1)	2354	2.75 (10.42)	0.421 (0.256)	16.60 (3.27)	
Standard Power Take-ff speed (540 rpm)					
44.1 (32.9)	2077	2.55 (9.64)	0.404 (0.246)	17.31 (3.41)	
VARYING POWER AND FUEL CONSUMPTION					
45.7 (34.1)	2354	2.75 (10.42)	0.421 (0.256)	16.60 (3.27)	Air temperature
39.7 (29.6)	2415	2.48 (9.37)	0.436 (0.265)	16.04 (3.16)	66°F (19°C)
30.0 (22.4)	2443	2.04 (7.74)	0.477 (0.290)	14.67 (2.89)	Relative humidity
20.1 (15.0)	2460	1.56 (5.91)	0.542 (0.330)	12.89 (2.54)	62%
10.2 (7.6)	2500	1.18 (4.46)	0.809 (0.492)	8.64 (1.70)	Barometer
....	2552	0.87 (3.31)	....	....	29.8" Hg (101.1 kPa)

Maximum Torque 132.1 lb-ft. (179.2 Nm) at 1249 rpm
Maximum Torque Rise 29.5%
Torque rise at 1850 engine rpm 16%

DRAWBAR PERFORMANCE
FUEL CONSUMPTION CHARACTERISTICS

Power Hp (kW)	Drawbar pull lbs (kN)	Speed mph (km/h)	Crank-shaft speed rpm	Slip %	Fuel Consumption lb/hp.hr (kg/kW.h)	Hp.hr/gal (kW.h/l)	Temp°F (°C) cool-ing med	Air dry both	Barom. inch Hg (kPa)
75% of Pull at Maximum Powe —Five Hours 10 h (1 FH) Gear									
30.3 (22.6)	2400 (10.67)	4.73 (7.62)	2420	3	0.554 (0.337)	12.62 (2.49)	air cld	46 (8)	29.5 (100.0)
MAXIMUM POWER IN SELECTED GEARS									
7th (4NL) Gear									
32.7 (24.4)	5115 (2275)	2.40 (3.86)	2397	15	0.546 (0.332)	12.80 (2.52)	air cld	41 (5)	29.6 (100.2)
8th (4NH) Gear									
36.5 (27.2)	4360 (19.39)	3.15 (5.07)	2350	8	0.528 (0.321)	13.24 (2.61)	air cld	41 (5)	29.6 (100.3)
9th (3FL) Gear									
38.8 (28.9)	4100 (18.24)	3.55 (5.7#)	2350	8	0.500 (0.304)	14.01 (2.76)	air cld	41 (5)	29.6 (100.2)
10th (3FH) Gear									
39.0 (29.1)	3210 (14.27)	4.56 (7.34)	2350	4	0.494 (0.301)	14.14 (2.79)	air cld	43 (6)	29.5 (100.0)
11th (2FL) Gear									
38.0 (28.3)	2455 (10.91)	5.80 (9.34)	2351	4	0.506 (0.308)	13.81 (2.72)	air cld	41 (5)	29.5 (100.0)
12th (2FH) Gear									
37.2 (27.7)	1860 (8.25)	7.49 (12.04)	2350	2	0.518 (0.315)	13.50 (2.66)	air cld	43 (6)	29.5 (100.0)
13th (3FL) Gear									
34.1 (25.4)	1320 (5.88)	9.67 (15.57)	2350	1	0.565 (0.343)	12.38 (2.44)	air cld	43 (6)	29.5 (100.0)

TRACTOR SOUND LEVEL WITHOUT CAB	dB(A)
Maximum sound level - in 10th (1FH) gear	94.6
Bystander in 16th (4FH) gear	81.4

Location of Test: ISMA Via Milano 43, 24047 Treviglio BG Italy

Dates of Test: February, 1996

Manufacturer: S+L+H S.p.A. V.le F. Cassani 15, 24047 Treviglio BG Italy

FUEL OIL and TIME: Fuel No. 2 Diesel **Cetane No.** NA **Specific gravity converted to 60°/60° F** *(15°/15°C)* 0.839 **Fuel weight** 6.99 lbs/gal *(0.838 kg/l)* **Oil SAE** 30 **API service classification** SE/CD **Oil consumption for 10 hours** 0.57 lb *(260 gm)* **Transmission and hydraulic lubricant** AKROS Multi 95 fluid **Front axle lubricant** SAE 95 API GL-4

ENGINE: Make S+L+H Diesel **Type** three cylinder vertical **Serial No.** 1732 **Crankshaft** lengthwise **Rated rpm** 2350 **Bore and stroke** 4.134" × 4.547" *(105 mm × 115.5 mm)* **Compression ratio** 17.1 to 1 **Displacement** 183 cu in *(3000 ml)* **Starting system** 12 volt **Lubrication** pressure **Air cleaner** two paper elements **Oil filter** one full flow cartridge **Oil cooler** radiator for crankcase oil **Fuel filter** one paper element **Muffler** vertical **Cooling medium temperature control** air cooled

CHASSIS: Type front wheel assist **Serial No.** 001032 **Tread width** rear 51.8" *(1315 mm)* to 55.1" *(1410 mm)* front 52.8" *(1340 mm)* to 60.6" *(1540 mm)* **Wheel base** 80.9" *(1926 mm)* **Hydraulic control system** direct engine drive **Transmission** selective gear fixed ratio **Nominal travel speeds mph** ***(km/h)*** first 0.70 *(1.13)* second 0.86 *(1.39)* third 1.11 *(1.78)* fourth 1.37 *(2.21)* fifth 1.76 *(2.83)* sixth 2.17 *(3.50)* seventh 2.78 *(4.48)* eighth 3.45 *(5.56)* ninth 3.85 *(6.20)* tenth 4.77 *(7.68)* eleventh 6.10 *(9.82)* twelfth 7.58 *(12.20)* thirteenth 9.75 *(15.69)* fourteenth 12.08 *(19.44)* fifteenth 15.47 *(24.89)* sixteenth 19.01 *(30.60)* reverse 0.82 *(1.32)*, 1.30 *(2.10)*, 2.07 *(3.33)*, 3.27 *(5.26)*, 4.53 *(7.29)*, 7.20 *(11.59)*, 11.48 *(18.48)*, 18.12 *(29.17)* **Clutch** single dry disc operated by foot pedal **Brakes** wet multiple disc hydraulically operated by two foot pedals which can be locked together **Steering** hydrostatic **Power take-off** 540 rpm at 2077 engine rpm **Unladen tractor mass** 4885 lb *(2215 kg)*

REPAIRS AND ADJUSTMENTS: No repairs or adjustments

REMARKS: All test results were determined from observed data obtained in accordance with official OECD test procedures. The performance results on this summary were taken from OECD tests conducted under the Code 1 Standard Test Code procedure.

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Fig. 2.10. Continued.

DRAWBAR PERFORMANCE
(UNBALLASTED—FRONT DRIVE ENGAGED)
MAXIMUM POWER IN SELECTED GEARS

Power Hp (kW)	Drawbar pull lbs (kN)	Speed mph (km/h)	Crankshaft speed rpm	Slip %	Fuel Consumption lb/hp hr (kg/kW·h)	Fuel Consumption Hp hr/gal (kW·h/l)	Temp °F (°C) cooling med	Temp °F (°C) Air dry bulb	Barom inch Hg (kPa)
				3rd (L3) Gear					
32.74 (24.41)	4480 (19.93)	2.74 (4.41)	2248	14.71	0.648 (0.394)	10.83 (2.13)	189 (87)	58 (14)	28.96 (98.07)
				4th (L4) Gear					
35.13 (26.20)	3111 (13.84)	4.24 (6.82)	2205	8.55	0.630 (0.383)	11.14 (2.20)	192 (89)	61 (16)	28.96 (98.07)
				5th (H1) Gear					
37.19 (27.73)	3097 (13.77)	4.50 (7.25)	2206	8.49	0.592 (0.360)	11.86 (2.34)	191 (88)	65 (18)	28.96 (98.07)
				6th (H2) Gear					
36.73 (27.39)	1990 (8.85)	6.92 (11.14)	2202	5.09	0.601 (0.366)	11.69 (2.30)	191 (88)	68 (20)	28.96 (98.07)

DRAWBAR PERFORMANCE
(UNBALLASTED—FRONT DRIVE DISENGAGED)
FUEL CONSUMPTION CHARACTERISTICS

Power Hp (kW)	Drawbar pull lbs (kN)	Speed mph (km/h)	Crankshaft speed rpm	Slip %	Fuel Consumption lb/hp/hr (kg/kW·h)	Fuel Consumption Hp hr/gal (kW·h/l)	Temp °F (°C) cooling med	Temp °F (°C) Air dry bulb	Barom inch Hg (kPa)
				Maximum Power—6th (H2) Gear					
36.57 (27.27)	2051 (9.12)	6.69 (10.76)	2205	7.80	0.601 (0.366)	11.68 (2.30)	192 (89)	69 (21)	28.95 (98.04)
				75% of Pull at Maximum Power—6th (H2) Gear					
28.79 (21.47)	1540 (6.85)	7.01 (11.28)	2262	5.61	0.649 (0.395)	10.82 (2.13)	191 (88)	75 (24)	28.85 (97.70)
				50% of Pull at Maximum Power—6th (H2) Gear					
19.74 (14.72)	1024 (4.55)	7.23 (11.64)	2286	3.82	0.751 (0.457)	9.36 (1.84)	189 (87)	75 (24)	28.85 (97.70)
				75% of Pull at Reduced Engine Speed—7th (H3) Gear					
28.78 (21.46)	1533 (6.82)	7.04 (11.34)	1482	5.38	0.567 (0.345)	12.38 (2.44)	194 (90)	75 (24)	28.85 (97.70)
				50% of Pull at Reduced Engine Speed—7th (H3) Gear					
19.73 (14.71)	1027 (4.57)	7.21 (11.60)	1498	3.94	0.586 (0.357)	11.98 (2.36)	188 (85)	75 (24)	28.85 (97.70)
				MAXIMUM POWER IN SELECTED GEARS					
				5th (H1) Gear					
34.75 (25.91)	3094 (13.76)	4.21 (6.78)	2232	14.84	0.627 (0.381)	11.20 (2.21)	190 (88)	67 (19)	28.96 (98.07)
				6th (H2) Gear					
36.57 (27.27)	2051 (9.12)	6.69 (10.76)	2205	7.80	0.601 (0.366)	11.68 (2.30)	192 (89)	69 (21)	28.95 (98.04)

TRACTOR SOUND LEVEL WITHOUT CAB	Front Wheel Drive Disengaged dB(A)	Front Wheel Drive Engaged dB(A)
At 75% load in 5th (H1) Gear	98.0	98.5
Bystander in 8th (H4) Gear	88.5	—

REMARKS: All test results were determined from observed data obtained in accordance with official OECD, SAE and Nebraska test procedures. For the maximum power tests, the fuel temperature at the injection pump inlet was maintained at 136° F *(58°C)*. The performance figures on this summary were taken from a test conducted under the OECD Code II Restricted Standard Test Code procedure.

We, the undersigned, certify that this is a true and correct report of official Tractor Test No. **1702**, Summary 190, November 29, 1995.

LOUIS I. LEVITICUS
Engineer-in-Charge

L.L. BASHFORD
R.D. GRISSO
M.F. KOCHER
Board of Tractor Test Engineers

TIRES, BALLAST AND WEIGHT

	Tested Without Ballast
Rear Tires—No., size, ply & psi *(kPa)*	Two 14.9-28; 6; 12 *(85)*
Front Tires—No., size, ply & psi *(kPa)*	Two 8.3-24; 6; 20 *(140)*
Height of Drawbar	16.5 in *(420 mm)*
Static Weight with Operator—Rear	3388 lb *(1537 kg)*
—Front	2222 lb *(1008 kg)*
—Total	5610 lb *(2545 kg)*

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Fig. 2.10. Continued.

SUPPLEMENT TO NEBRASKA OECD TRACTOR TEST 1702—SUMMARY 190
NEW HOLLAND 3930 8x8 DIESEL
8 SPEED

CHASSIS SERIAL NUMBERS *091151B* AND HIGHER

POWER TAKE-OFF PERFORMANCE

Power HP (kW)	Crankshaft speed rpm	Gal/hr (l/h)	lb/hp.hr (kg/kWh)	Hp.hr/gal (kWh/l)	Mean Atmospheric Conditions
MAXIMUM POWER AND FUEL CONSUMPTION					
Rated Engine Speed—(PTO speed—676 rpm)					
52.54 (39.18)	2200	3.25 (12.31)	0.438 (0.267)	16.15 (3.18)	
Standard Power Take-off Speed (540 rpm)					
46.43 (34.62)	1757	2.71 (10.26)	0.414 (0.252)	17.13 (3.37)	
VARYING POWER AND FUEL CONSUMPTION					
52.54 (39.18)	2200	3.25 (12.31)	0.438 (0.267)	16.15 (3.18)	Air temperature
46.38 (34.59)	2291	3.09 (11.71)	0.472 (0.287)	15.00 (2.95)	83°F (28°C)
35.49 (26.46)	2320	2.63 (9.94)	0.524 (0.319)	13.51 (2.66)	Relative humidity
23.85 (17.77)	2344	2.08 (7.86)	0.617 (0.375)	11.48 (2.26)	61%
11.86 (8.84)	2363	1.57 (5.93)	0.936 (0.569)	7.57 (1.49)	Barometer
0.42 (0.31)	2368	1.10 (4.17)	18.757 (11.416)	0.38 (0.07)	28.93"Hg (97.96 kPa)

Maximum Torque 159 lb-ft. (188 Nm) at 1699 rpm
Maximum Torque Rise 10.5%
Torque rise at 1757 rpm 10%

Location of Test: Nebraska Tractor Test Laboratory, University of Nebraska, Lincoln, Nebraska 68583-0832

Dates of Test: September 29, 1998

Manufacturer: New Holland N.A., 500 Diller Avenue, New Holland PA 17557

FUEL and OIL: Fuel No. 2 Diesel **Specific gravity converted to 60°/60° F** *(15°/15°C)* 0.8506 **Fuel weight** 7.082 lbs/gal *(0.849 kg/l)*

ENGINE: Make Ford New Holland Diesel **Type** three cylinder vertical with turbocharger **Serial No.** *332T/JD*785681* **Crankshaft** lengthwise **Rated engine speed** 2200 **Bore and stroke** 4.4" × 4.2" *(111.8 mm × 106.7 mm)* **Compression ratio** 17.5 to 1 **Displacement** 192 cu in *(3141 ml)*

CHASSIS: Type front wheel assist **Serial No.** *103947B*

NOTE: The performance figures on this summary apply to tractor chassis serial numbers *091151B* and higher.

We, the undersigned, certify that this is a true and correct supplement to official Tractor Test No. **1702**, Summary 190, October 19, 1998.

LEONARD L. BASHFORD
Director

M.F. KOCHER
R.D. GRISSO
G.J. HOFFMAN
Board of Tractor Test Engineers

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Fig. 2.10. Continued.

THREE POINT HITCH PERFORMANCE (OECD Static Test)

CATEGORY: I		
Quick Attach: none		
Maximum Force Exerted Through Whole Range:	3056 lbs	*(13.6 kN)*
i) Opening pressure of relief valve:	NA	
Sustained pressure of the open relief valve:	2590 psi	*(178 bar)*
ii) Pump delivery rate at minimum pressure:	9.3 GPM	*(35.2 l/min)*
iii) Pump delivery rate at maximum hydraulic power:	8.1 GPM	*(30.7 l/min)*
Delivery pressure:	2250 psi	*(155 bar)*
Power:	10.6 HP	*(7.9 kW)*

THREE POINT HITCH PERFORMANCE (SAE Static Test)

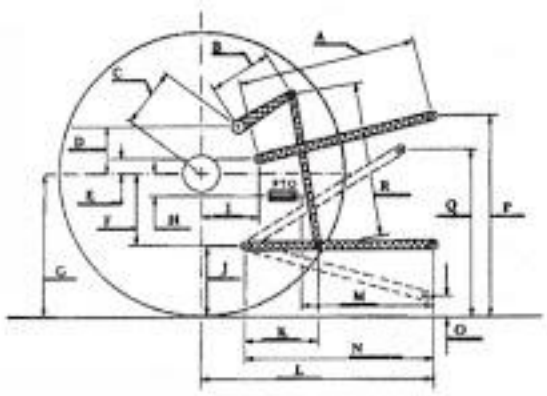
Observed Maximum Pressure psi. *(bar)*	2600 *(179)*
Location	remote outlet
Hydraulic oil temperature °F *(°C)*	169 *(76)*
Location	rear axle sump
Category	1
Quick attach	none

As per current SAE test procedures

Hitch point distance to ground level in. *(mm)*	8.3 *(211)*	13.0 *(330)*	17.7 *(450)*	22.4 *(569)*	27.2 *(691)*	32.1 *(815)*
Lift force on frame lb	3056	3353	3524	3542	3434	3245
Lift force on frame *(kN)*	*(13.6)*	*(14.9)*	*(15.7)*	*(15.8)*	*(15.3)*	*(14.4)*

As per current ASAE test procedures

Hitch point distance to ground level in. *(mm)*	8.3 *(211)*	13.0 *(330)*	17.7 *(450)*	22.4 *(569)*	27.2 *(691)*	32.1 *(815)*
Lift force on frame lb.	3271	3589	3772	3791	3676	3473
Lift force on frame *(kN)*	*(14.5)*	*(16.0)*	*(16.8)*	*(16.9)*	*(16.3)*	*(15.4)*



HITCH DIMENSIONS AS TESTED—NO LOAD

	inch	*mm*
A	28.3	*719*
B	10.0	*254*
C	12.9	*327*
D	10.1	*257*
E	7.5	*191*
F	8.0	*203*
G	24.0	*610*
H	4.7	*120*
I	8.7	*222*
J	16.0	*407*
K	18.9	*481*
L	36.7	*931*
M	20.9	*530*
N	34.0	*864*
O	8.0	*203*
P	34.1	*867*
Q	33.1	*841*
R	29.1	*740*



FORD 3930 8 X 8 DIESEL

Agricultural Research Division
Institute of Agriculture and Natural Resources
University of Nebraska–Lincoln
Darrell Nelson, Dean and Director

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TABLE 2.1. Tire Static Load Limits, kg[lb], at Various Inflation Pressures, kPa [psi].

	Diagonal (bias) ply drive-wheel tires. Speeds limited to 40 km/hr [25 MPH]						
Pressures	80 [12]	110 [16]	140 [20]	150[22]	170 [24]	180[26]	190 [28]
12.4-24	710[1570]	850[1870](**4**)	975[2150]	1030[2270]	1090[2400](**6**)	1120[2470]	1180[2600]
14.9-24	*1000[2200]	1180[2600]	1360[3000](**6**)	1450[3200]	1500[3300]	1600[3520](**6**)	1650[3640]
17.5L-24	1180[2600]	1400[3080](**6**)	1600[3520]	1650[3640](**8**)	1750[3860]	1850[4080]	1900[4180](**10**)
12.4-28	775[1710]	900[1980](**4**)	1030[2270]	1090[2400]	1150[2540](**6**)		
14.9-28	*1060[2340]	1285[2830]	1450[3200](**6**)	1550[3420]	1600[3520]	1700[3740](**8**)	1800[3960]
18.4-28	*1550[3420]	1850[4080](**6**)	2120[4680](**8**)	2240[4940]	2360[5200]	2430[5360](**10**)	2575[5680]
14.9-30	*1120[2470]	1320[2910]	1500[3300](**6**)	1600[3520]	1650[3640]	1750[3860](**8**)	1800[3960]
18.4-30	*1600[3520]	1900[4180]	2180[4800](**8**)	2300[5080]	2430[5360]	2500[5520](**10**)	
18.4-34	*1700[3740]	2000[4400](**6**)	2300[5080](**8**)				
14.9-38	*1250[2760]	1500[3300]	1700[3740](**6**)				
18.4-38	*1800[3960]	2120[4680](**6**)	2430[5360](**8**)	2575[5680]	2725[6000]	2900[6400](**10**)	3000[6600]
18.4-42	*1900[4180]	2240[4940]	2575[5680](**8**)	2725[6000]	2900[6400]	3000[6600](**10**)	
20.8-42	*2300[5080]	2725[6000]	3150[6950]	3350[7400](**10**)			

Bold figures in parentheses denote ply rating for which the loads and inflations are maximum.
* marked values are for duals only.
When used as duals, tire loads must be reduced to 0.88 of table loads, 0.82 if triples.
For transport service and operations which do not require sustained high tire torque, the table loads above may be increased 33% for speeds up to 16 km/hr[10 MPH]; 22% up to
[20 MPH]; none for 40 km/hr[25 MPH]

	Diagonal (bias) steering-wheel tires. Speeds limited to 40 km/hr [25 MPH]						
Pressures	170[24]	190[28]	220[32]	250[36]	280[40]	300[44]	Maximum
7.50-16 SL	450[990]	500[1100]	545[1200]	600[1320]	630[1390]	670[1480](**6**)	775[1710]@390 k
11-16 SL	850[1870]	950[2090]	1030[2270](**6**)	1120[2470]	1180[2600](**8**)	1250[2760]	1550[3420]@410
11L-16 SL	670[1480]	750[1650]	800[1760]	875[1930]	950[2090]	1000[2200](**10**)	1250[2760]@440
11-24 SL	1090[2400]	1215[2680]	1320[2910]	1450[3200]	1550[3420](**8**)	1650[3640]	1750[3860]@333

For above tires used in cycling loading service at speeds below 8 km/hr[5 MPH], loads may be increased 67%
For transport speeds, table values may be increased 50% up to 16 km/hr[10 MPH]; 28% up to 24 km/hr[15 MPH]; 11% up to 32 km/hr[20 MPH]

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TABLE 2.1. Continued

Radial ply drive-wheel tires. Speeds limited to 48 km/hr [30 MPH]							
Pressures	40[6]	60[8]	70[10]	80[12]	100[14]	110[16]	120[18]*
13.6R24	630[1390]	750[1650]	850[1870]	950[2090]	1030[2270]	1120[2470]	**1180[2600]**
14.9R24	750[1650]	875[1930]	1000[2200]	1120[2470]	1215[2680]	1320[2910]	**1400[3080]**
16.9R24	900[1980]	1060[2340]	1215[2680]	1360[3000]	1600[3520]	1500[3300]	**1700[3740]**
14.9R28	800[1760]	950[2090]	1060[2340]	1180[2600]	1400[3080]	1320[2910]	**1500[3300]**
16.9R28	975[2150]	1150[2540]	1320[2910]	1450[3200]	1700[3740]	1600[3520]	**1850[4080]**
14.9R30	825[1820]	975[2150]	1120[2470]	1215[2680]	1360[3000]	1450[3200]	**1550[3420]**
16.9R30	1000[2200]	1180[2600]	1360[3000]	1500[3300]	1650[3640]	1750[3860]	**1900[4180]**
16.9R38	1120[2470]	1320[2910]	1500[3300]	1700[3740]	1850[4080]	2000[4400]	**2120[4680]**
18.4R38	1360[3000]	1600[3520]	1800[3960]	2000[4400]	2180[4800]	2360[5200]	**2575[5680]**
20.8R38	1650[3640]	1950[4300]	2180[4800]	2430[5360]	2650[5840]	2900[6400]	**3075[6800]**
18.4R42	1400[3080]	1700[3740]	1900[4180]	2120[4680]	2300[5080]	2500[5520]	**2725[6000]**
20.8R42	1700[3740]	2060[4540]	2300[5080]	2575[5680]	2800[6150]	3075[6800]	**3250[7150]**

Bold numbers denote maximum loads for the number of star(*) markings molded on the tire, referred to as 1-star, 2-star, 3-star.
For transport service above 32 km/hr[20 MPH], inflation pressure should be 60 kPa[8 psi] or above .
When used as duals, tire loads must be reduced to 0.88 of table loads, 0.82 if triples.
For transport service and operations that do not require sustained high torque, the table loads may be increased 34% for speeds up to 16 km/hr[10 MPH]; 11% up to 24 km/hr[15 MPH]; 7% up to 32 km/hr[20 MPH]; none for over 32 km/hr[25 MPH]

Radial ply metric drive-wheel tires. Speeds limited to 48 km/hr [30 MPH]							
Pressures	40[6]	60[9]	80[12]	100[15]	120[17]	160[23]	Maximum
480/70R30	1180[2600]	1400[3080]	1650[3640]	1900[4180]	2120[4680]134B	2575[5680]141B	3550[7850]152B@320 kPa[46 psi]
380/85R34	1030[2270]	1250[2760]	1450[3200]	1650[3640]	1850[3860]127B	2300[5080]137B	2650[5840]142B@240 kPa[35 psi]
520/70R38	1500[3300]	1800[3960]	2120[4680]	2360[5200]	2725[6000]143B	3350[7400]150B	

All the notes above for radial tires apply to metric radials also except the bold numbers are maximum for the Load Index and Speed Symbol shown.
These tires may be used for cyclic loading service. The above loads may be increased 70% (with a 40 kPa[6 psi] increase in pressure) for speeds under 8 km/hr[5 MPH] for op

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An example metric tire marking is:

380/85 R 34

where: 380 is the nominal section width in mm,
85 is the aspect ratio (100 × section height/section width).
R indicates radial; B for bias; D for diagonal construction,
34 is the nominal rim diameter in inches.

Metric tires also have designations for speed and load limits.

Speed Symbol	Limiting Speed	
A2	10 km/hr	[5 MPH]
A3	15 km/hr	[10 MPH]
A5	25 km/hr	[15 MPH]
A6	30 km/hr	[20 MPH]
A8	40 km/hr	[25 MPH]
B	50 km/hr	[30 MPH]

The strength of a metric tire is reported by the Load Index. This index is a numerical code associated with the maximum load that a tire can carry at the speed indicated by its Speed Symbol under specified conditions. The Service Designation includes both codes and is marked for example as 143 B.

The machinery manager can use Table 2.1 to insure long tire life by honoring the load limits for specific inflation pressures when adding ballast to tractor tires. Notice in Table 2.1 that the allowable load capacities are reduced with lower inflation pressures. The loads with metric units (kg) are in mass units and must be multiplied by g to get a force. The notes indicate modifications in the use of this table.

Excessive torque can cause a drive-wheel tire to slip on the rim and lose pressure. The maximum pull at the tire-ground surface contact point should not exceed the rated static load excluding momentary and occasional peak loads.

Table 2.2 lists the load limits for drive wheels having cyclic loading such as self-propelled combines, cotton pickers, sprayers and any other self-driven implement that gains or loses weight as it operates. Ballast is usually not needed for these tires nor is tire torque a problem. Soil compaction may be a serious problem however as these machines may have to operate when the soil is most susceptible to compaction. The machinery manager can refer to Table 2.2 and select the lowest tire pressure possible for the loads imposed and the increased tire deflection will spread the existing load over a greater area and limit the compaction. The note for Table 2.2 cautions that the load limits for a tire as one of a dual pair is less than that for a single tire as occasionally substantial overload may shift onto only one tire of the pair.

TABLE 2.2. Tire Static Load Limits, kg[lb], at Various Inflation Pressures, kPa[psi]. Diagonal (bias) ply drive wheel tires used in cycling loading field service. Speeds limited to 8 km/hr[5 MPH].

Tire size	Ply rating	Max. loads	Infl. pressure
13.6-28	6	2400 [5300]	190 [28]
	8	2810 [6150]	250 [36]
	10	3180 [7000]	320 [46]
16.9-34	6	3360 [7400]	170 [24]
	8	3960 [8800]	220 [32]
	10	4420 [9700]	250 [36]
18.4-34	8	4300 [9500]	180 [26]
20.8-34	8	4960 [10900]	170 [24]
	10	5620 [12300]	190 [28]
11.2-3	8	41780 [3900]	170 [24]
13.6-3	8 6	2810 [6150]	190 [28]
15.5-3	8 6	2990 [6600]	180 [26]
16.9-3	8 6	3560 [7800]	170 [24]
	8	4180 [9250]	220 [32]
18.4-38	8	4540 [10000]	180 [26]
	10	5420 [12000]	230 [34]
	12	6080 [13400]	290 [42]
20.8-38	8	5240 [11500]	170 [24]
	10	5900 [13000]	190 [28]
	14	7250 [16000]	290 [42]
20.8-42	10	6250 [13800]	190 [28]

Note: When used as duals, tire loads must be reduced to 0.88 of table loads.

Fuel Consumption

Estimates of fuel consumption are of interest to farm machinery managers. Table 2.3 estimates fuel consumption for full and part loads. The data were compiled from Nebraska Tractor Test data before 1980 for gasoline and LP gas fuels. The data for diesels were reported in 1984 by A. Khalilian, D. Batchelder, K. Self, and J. Summers (Agricultural Engineering Department, Oklahoma State University). These data are for new tractors prepared for official testing. Aged tractors might not equal these efficiencies. The coefficient of variation for this data was 9.1%, which means two-thirds of all the data would be contained in a range ± 9.1% about the mean.

The use of Table 2.2 is illustrated by the following:

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different pressure, 210 kPa [30 psi], and drop down to read a different coefficient of 0.16. At rated inflation pressures, extra wide tires could have as much as 50% less rolling resistance on sand and 50% more on concrete.

Mounted and semimounted implements may have rolling resistance too. If some of the implement weight is carried on the tractor while operating, that weight times the coefficient of rolling resistance (RR) for the rear tractor tires is really implement rolling resistance. Such rolling resistance need not be included when computing drawbar pull for use in Fig. 2.11.

Power requirements can be quoted in many different ways depending on the characteristics of the operation and the machine. Quite often a force instead of a power requirement is reported to remove the effect of variations in forward speed. The variation due to different sizes of implements is removed by reporting draft per unit of effective width, per machine unit, or per row. Consequently, both speed and size variables are eliminated when technical work or energy requirements are quoted.

The unit of energy in the SI system is the joule, defined as one newton of force exerted through one metre of distance (J = N·m). In agriculture, the product of power and time per area has utility and is the energy unit used. A manager can estimate power requirements to obtain a certain capacity, or conversely, given the power available, estimate the capacity. The common unit for field work is kW·hr/ha [HP·hr/a]. For harvesters where yield affects power so greatly, an energy unit of kW·hr/t [HP·hr/T] is more appropriate. Rolling and functional resistances are combined for most tillage and ground-driven machine reports, while functional requirements only are reported for most PTO- and self-propelled machines.

Table 2.5 lists power, draft, and energy requirements for many field machines. Compiled from many sources and including estimates, it attempts to report ranges in which 90% of all actual operations would be included. These values are not expected to be very descriptive for any individual operation. A machinery manager can make determinations for a specific operation through use of an inexpensive pull meter (Fig. 2.13).

An example can illustrate how the power requirements for a field operation can be computed: Estimate the total power required for a 4-m [13-ft] light tandem disk harrow pulled behind a 4-m [13-ft], 500 kg [1100 lb] stalk chopper equipped with two 6.50-16 tires inflated to 170 kPa [24 psi]. Operating speed is 8 km/hr [5 MPH].



Fig. 2.13. Hydraulic pull meter.

Stalk chopper: From Table 2.5, the average power is 11 kW/m [4.5 HP/ft].

PTOP = 4 × 11 = 44 kW [13 × 4.5 = 58.5 HP]

From Fig. 2.12, the coefficient of RR at 170 kPa [24 psi] and for a tire diameter of 66 cm [0.9 x (16 + 6.5 + 6.5) = 26 in.] is 0.18.

$$\text{DBP} = \frac{0.18 \times 500 \times (9.807/1000) \times 8}{3.6} = 1.96 \text{ kW}$$

$$\left[\frac{0.18 \times 1100 \times 5}{375} = 2.64 \text{ HP} \right]$$

Disk harrow: From Table 2.4, the average force is 2.05 kN/m [140 lb/ft]. Total draft is 8.2 kN [1820 lb].

DBP = 8.2 × 8/3.6 = 18.22 kW [1820 × 5/375 = 24.3 HP]

Total power is 64.18 kW [85.44 HP].

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Table 2.5. Field Machinery Power Requirements at 4.8 km/hr [3 MPH].

Machine	Draft, Force per Unit Width kN/m [lb/ft]		Energy or Work kW·hr/ha [HP·hr/a]	
Tillage Implements				
Plow, moldboard or disk				
(18-cm [7-in.] depth)				
light soils	3.2-6.3	[220-430]	8.7-17.5	[4.7-9.5]
medium soils	5.3-9.5	[350-650]	14.6-25.8	[7.9-14]
heavy soils	8.5-16.6	[580-1140]	22.1-46.1	[12-25]
Vertical disk plow				
(8-13 cm [3-5 in.] deep)	2.6-5.8	[180-400]	7.4-16.2	[4.0-8.8]
Lister, hard ground				
(1 m [38 in.] spacing)	5.8-14.6/unit	[400-1000/unit]	4.18-12.5	[2.6-6.8]
Subsoiler (40-cm [16-in.] deep)				
2-m [6-ft] spacing)				
light soils	16.0-26.3/unit	[1100-1800/unit]	7.2-12.0	[3.9-6.5]
medium soils	23.3-36.5/unit	[1600-2500/unit]	10.1-15.7	[5.5-8.5]
Land plane	4.4-11.7	[300-800]	12.2-31.3	[6.6-17]
Chisel plow				
(18-23 cm [7-9 in.] deep)	2.9-13.1	[200-900]	8.1-36.9	[4.4-20]
Field cultivator				
(8-13 cm [3-5 in.] deep)	0.9-4.4	[60-300]	2.4-12.0	[1.3-6.5]
Blade cultivator				
(2 m [6.5 ft] blade)				
7.5 cm [3 in.] deep	4.0-4.7	[275-320]	6.9-13	[6-7]
Disk harrow				
single gang	0.7-1.5	[50-100]	2.0-4.0	[1.1-2.2]
light tandem	1.5-2.6	[100-180]	4.0-7.4	[2.2-4.0]
heavy tandem	80-150% of weight		7.4-12.9	[4.0-7.0]
Spike-tooth harrow	0.3-0.9	[20-60]	0.7-2.4	[0.4-1.3]
Spring-tooth harrow	1.0-4.4	[70-300]	2.1-12.2	[1.7-6.6]
Rod weeder	0.5-1.8	[35-120]	1.5-4.8	[0.8-2.6]
Land roller or packer	0.3-0.9	[18-60]	0.7-2.4	[0.4-1.3]
Rotary tiller[a]				
(8-10 cm [3-4 in.] forward slice)	12.2-24.5 kW/m	[5-10 HP/ft]	25.8-51.6	[14-28]
Rotary harrow	10.0-15.0 kW/m	[4-6 HP/ft]	20.0-30.0	[11-17]
Seeders				
Row planter (1-m [38 in.] spacing)	0.45-0.80/row	[100-180/row]	1.1-2.4	[0.6-1.3]
fertilizer attachs.	1.1-1.8/row	[250-400/row]	3.1-5.2	[1.7-2.8]
Grain drill	1.0-1.6	[30-100]	1.1-3.9	[0.6-2.1]
No-till drill	2.3-3.5	[160-240]	6.4-9.7	[3.5-5.3]
Air seeder (draft only)	3.5-3.9	[240-270]	9.7-10.8	[5.3-6.0]
Chemical Applicators				
NH_3 applicator	5.1-7.3	[350-500]	4.4-6.5	[2.4-3.5]
Sprayer (10-80 cm[32 in.])[b]	0.2 kW	[0.3 HP]	0.02-.04	[.01-.02]
Broadcast distributor	0.7-2 kW	[1-3 HP]	0.2-0.4	[0.1-0.2]
Field distributor	0.3-1.2	[20-80]	0.9-3.1	[0.5-1.7]
Cultivation				
Row cultivators				
shallow	0.6-1.2	[40-80]	1.6-3.3	[0.9-1.8]
deep (8 cm [3 in.])	0.9-1.8	[60-120]	2.4-4.8	[1.3-2.6]
Rotary hoe	0.4-0.9	[30-60]	1.3-2.4	[0.7-1.3]
	PTO Power kW/m [HP/ft]		Energy or Work kW/·hr/ha [HP·hr/a]	
Grain Harvesting				
Windrower (swather)[b]	1.4-1.9	[0.6-0.8]	2.9-4.0	[1.6-2.2]
Combines				
small grain	3.6-12.0	[1.5-4.9]	7.5-25	[4.1-13]
corn (0.76 m [30 in.] row)	7-11/row	[10-15/row]	20-30	[11-16.5]
Corn picker[b]	1.5-3.7/row	[2-5/row]	4.4-8.8	[2.4-4.8]

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Table 2.5. Continued.

	PTO Power kW/m [HP/ft]		Energy or Work kW/-hr/ha [HP-hr/a]	
Forage Harvesting				
Mower, cutterbar[b]	1.0-1.2	[0.4-0.5]	2-2.5	[1.1-1.4]
Mower, rotary disc[b]	3.5-6.5	[1.4-2.7]	7.3-13.5	[3.9-7.4]
Conditioner, cutterbar[b]	3.7-4.9	[1.5-2.0]	7.7-10.2	[4.1-5.5]
Conditioner, rotary disc[b]	5.6-10.4	[2.2-4.2]	11.6-21.7	[6.1-11.6]
Side-delivery rake[b]	0.5-0.8	[0.2-0.3]	1.0-1.7	[0.6-0.8]
Stalk chopper[b]	4.9-17.1	[2.0-7.0]	6.5-20	[3.5-11]
Baler, rectangular[b]				
hay			1.0-1.5	[1.2-2.7]
straw			1.4-1.5	[1.7-2.7]
Baler, round[b]			1.6-1.9	[1.9-2.3]
Forage harvester, flail[b]			0.9-2.0	[1.1-2.5]
Forage harvester, shear bar[b]				
green forage			0.8-2.0	[1.0-2.5]
wilted forage			1.2-4.1	[1.5-5.0]
hay, straw			1.6-4.1	[2.0-5.0]
corn ensilage			1.2-3.3	[1.5-4.0]
Tub grinder			3.0-9.1	[3.7-11.1]
	PTO Power kW/row [HP/row]		Energy or Work kW-hr/ha [HP-hr/a]	
Special Crop Harvesters				
Cotton picker, spindle				
(single pick,1-m [38-in.] rows)	7.5-11.2	[10-15]	15.6-23.3	[8.5-12.6]
Cotton stripper[b]				
(1-m [38-in.] rows)	1.5-2.2	[2-3]	3.1-4.6	[1.7-2.5]
Beet topper[b]				
(0.56-m [22-in.] rows)	3.7-5.2	[5-7]	7.7-10.8	[4.2-5.9]
Beet lifter				
(0.56-m [22-in.] rows)	1.5-3.0	[2-4]	13-26	[7.1-14.1]
draft force	2-4 kN/row	[450-900 lb/row]		
Potato harvester				
(1-m [38-in.] rows)	0.7-1.5	[1-2]	14.4-23.5	[7.8-12.8]
draft force	2.2-3.5 kN/row	[500-800 lb/row]		

[a]Has negative rolling resistance.

[b]Does not include implement or wagon rolling resistance.

Part-Load Operation

C. J. Ricketts and J. A. Weber (University of Illinois) found a rather uniform distribution of the time an "average" tractor spends at each power loading. The data in Table 2.6 are based on their work with a 35 kW [48 HP] tractor used in actual on-farm work.

TABLE 2.6. Distribution of Tractor Power Loading

% Maximum Power	% Total Time
Over 80	16.8
80-60	23.9
60-40	22.6
40-20	17.5
Less than 20	19.2

It would appear that the power performance of tractors at part load is a very important consideration for good power and machinery management. The effects on fuel efficiency and wear are of primary interest. Ricketts and Weber indicated the fuel efficiency of their gasoline tractor with a diagram similar to that in Fig. 2.14. Lines of constant fuel efficiency are superimposed on the horsepower-engine speed graph. The dotted lines indicate the performance when the governor control or hand-operated speed control lever is set at fractions of the full-open position. Potential fuel economy is demonstrated by considering a partial load of 40% on the tractor. If the governor control is set at full-open the fuel efficiency is about 12%. By adjusting the transmission gear ratio it is possible to reduce the governor control setting to one-fourth open and still maintain the same forward speed and power output. In doing so the fuel efficiency will improve to 17%.

In a similar study, Samuel G. Huber and Benson J. Lamp (Ohio State University) found that although there are differences in individual tractors, considerable fuel savings can be realized by reducing the governor

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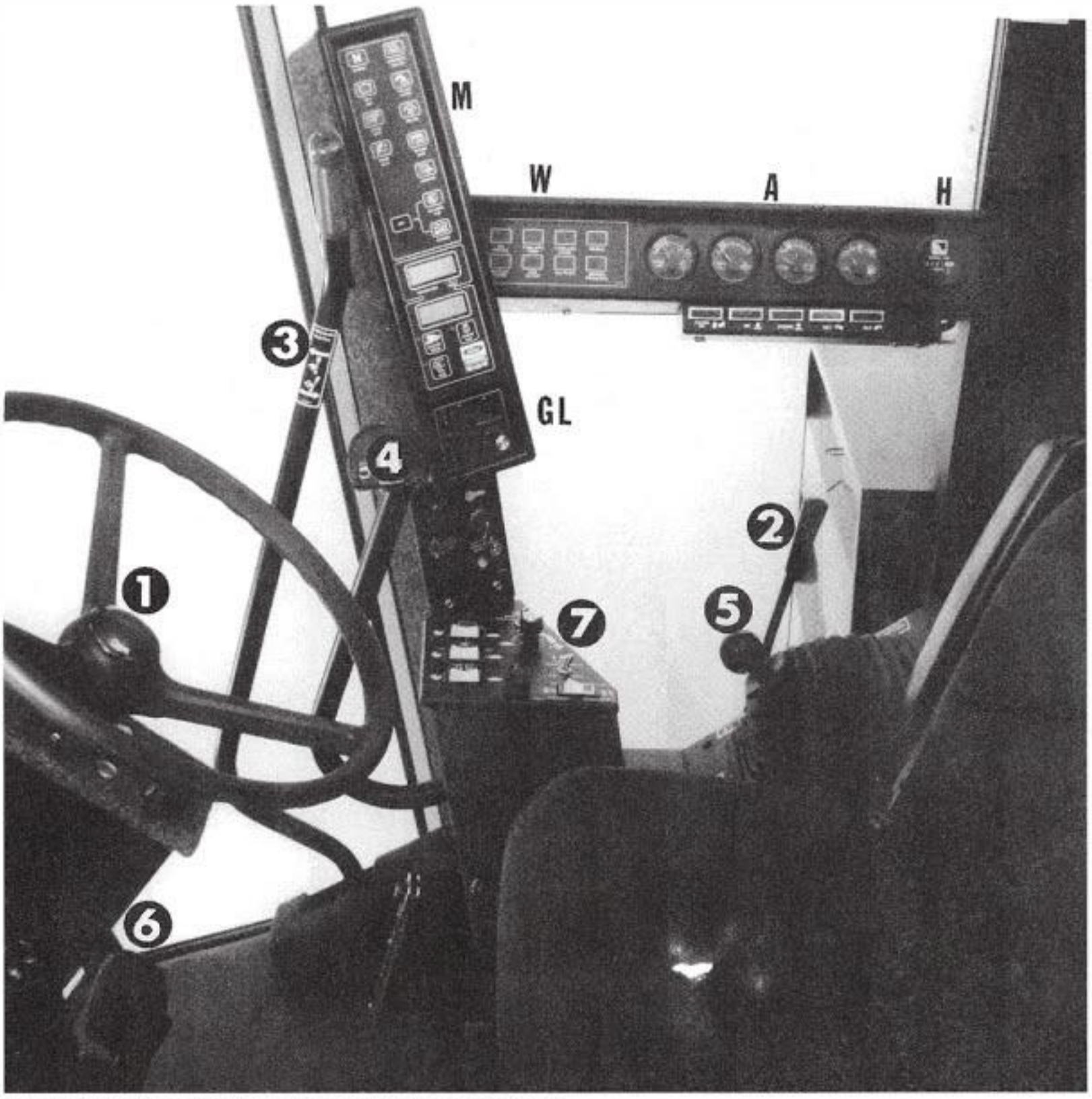


Fig. 3.1. Controls and instruments in a modern combine cab.

A speed control console (7) allows for the adjustment of combine cylinder, header drive, beater, and reel rpm. A grain loss monitor (GL) indicates the operating efficiency of the combine. A monitoring instrument panel (M) provides digital readings of ground speed; indicates engine, cylinder, and fan rpm; includes warning lights for the non-operation of the straw spreader or chopper, rear beater, tailings return elevator, clean grain elevator, cleaning fan and cylinder; shows the position of the unloading auger and stone trap; and indicates an overfull grain bin. A skilled operator will understand and make use of all the controls and instrumentation provided by the manufacturer.

The need for alertness increases with the size and complexity of machines. Small, simple machines may require only steering activities from an operator. Large, complex machines require only a little more attention to steering but much more activity in monitoring the machine's operation. In cultivating with a

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2-row machine it is rather easy to observe the effectiveness of the 10–12 shovels or sweeps; but with a 12-row cultivator there will be 60 to 72 different points to watch, many of which are far from the operator and difficult to see. In some critical operations such as seeding, where malfunction can mean unseeded areas producing no income, the costs of inattention can be substantial.

Operator Skill

The individualism of people is an important factor in labor performance. K. Von Bargen (University of Nebraska) found that differences in ability, motivation, alertness, and training of an operator can have significant effects on operator performance. In cases under similar field environments, one operator of a 4.27-m [14-ft] windrower was able to do 2 ha/day [5a/day] extra because among other things he could consistently average 15 cm [6 in.] greater width of cut than could the other operators. Fig. 3.2 shows a windrower operator undercutting about 15 cm [6 in.]. Fig. 5.7 shows an overlap of 10% for a wide tillage implement.

Von Bargen analyzed field times for several operator-machine combinations. He defined the potential capacity of the combinations as based on operating time plus the time required for turns, for travel between fields, and for delays due to necessary machine support activities. (This base is not directly comparable to field efficiency.) Time for the operator; for machine maintenance, service, and repair; and for undesirable delays were defined as idle or lost time.

Fig. 3.3, 3.4, and 3.5 show the variations in operator-machine performance. The points on the curves are to be read as percentage of total time in which the machine was operating at the given percentage of potential capacity. The areas under the curves represent total time and are equal to each other. The data for the operators are as follows:

Operator A. Age 29, experienced with balers, a former farm operator.

Operator E. Age 25, one season's experience with SP balers, general farm background, very adept mechanically.

Operator F. Age 17, no previous windrower experience, general farm background.

Operator H. Age 19, one season's experience in pull-type bale wagon operations, general farm background.

Operator I. Age 17, no previous experience with bale wagons, general farm background.

Operator J. Age 18, no windrowing experience, general farm background.

Operator K. Age 18, custom baling experience, general farm background.

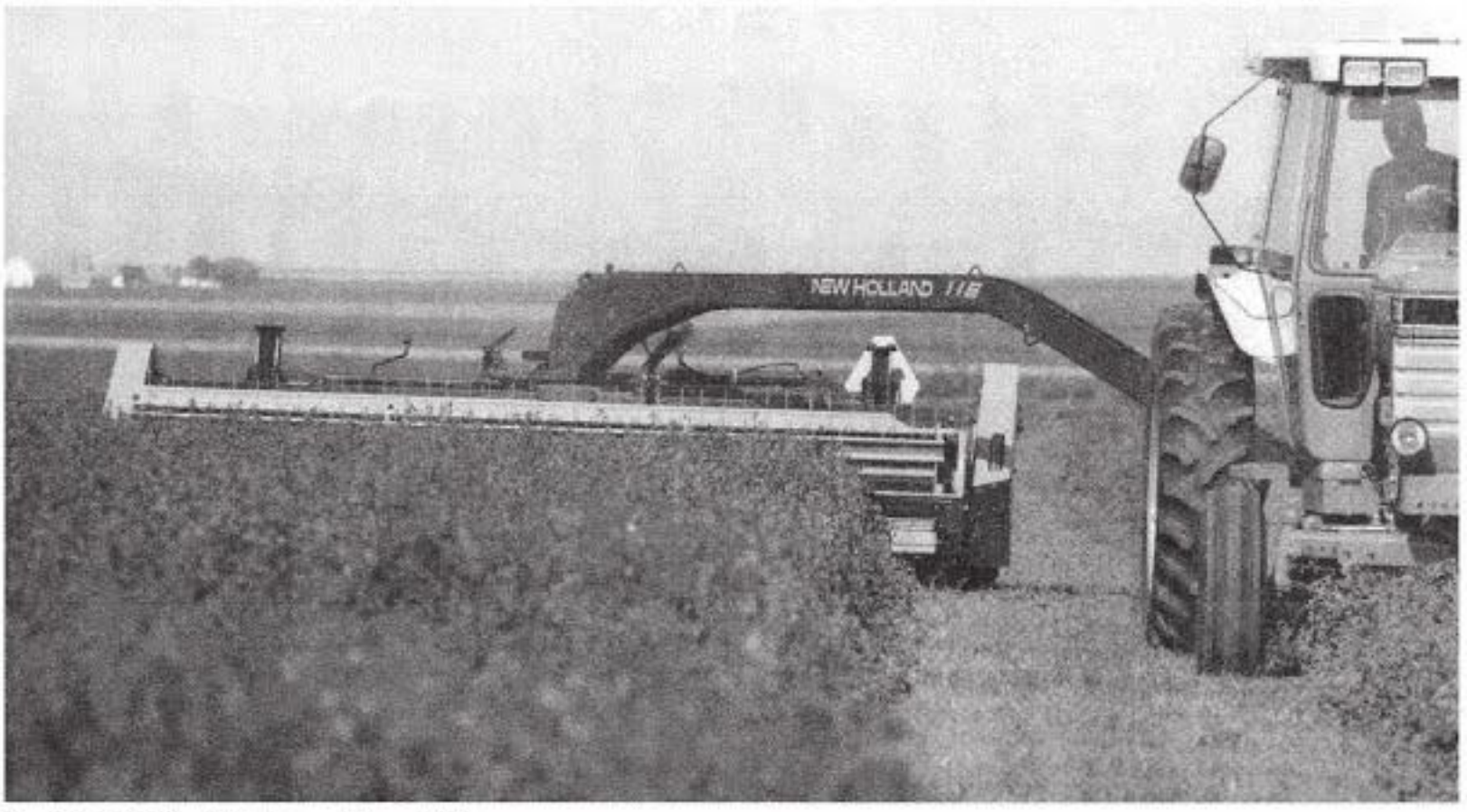


Fig. 3.2. A 93% effective cut, $E_w = 0.93$.

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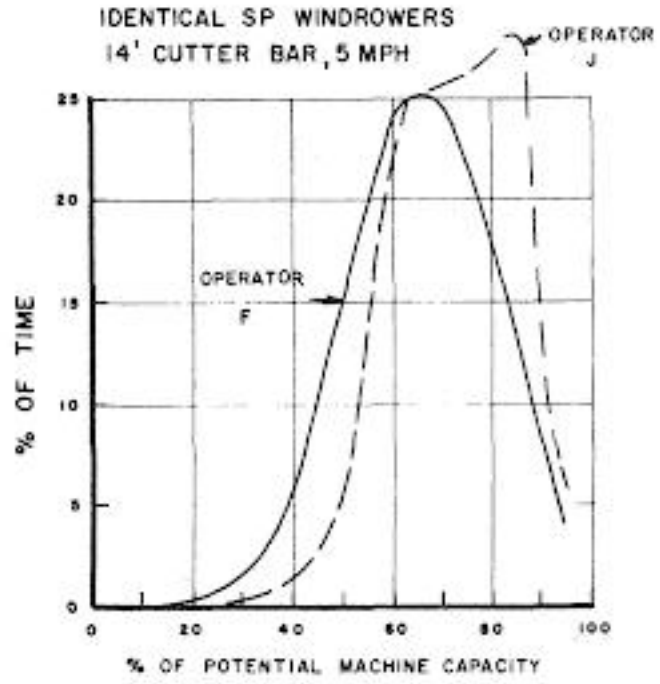


Fig. 3.3. Operator-machine performance, SP windrowers.

Good performance was defined as operating at 65% of potential capacity or higher. In Fig. 3.3, Operator J achieved this performance 69% of the time, while Operator F could attain this performance only 48% of the time as determined by comparing the areas under the curves. In Fig. 3.4 all three baler operators had their peak percent of time above 65%; but Operator E spent 66% of the total time above 65, while Operator K spent only 48%.

These curves can be misleading. For the bale wagons (Fig. 3.5), Operator H was classified as the superior operator even though Operator I spent a greater amount of time above the 65% mark. Operator H was able to load bales so fast that he wasted a considerable amount of time waiting for more bales from the baler, another illustration of the need for a systems approach to machinery management analyses. In general, this analysis tends to penalize operators who drove at faster field speeds. High field speeds reduce theoretical field or operating time relative to

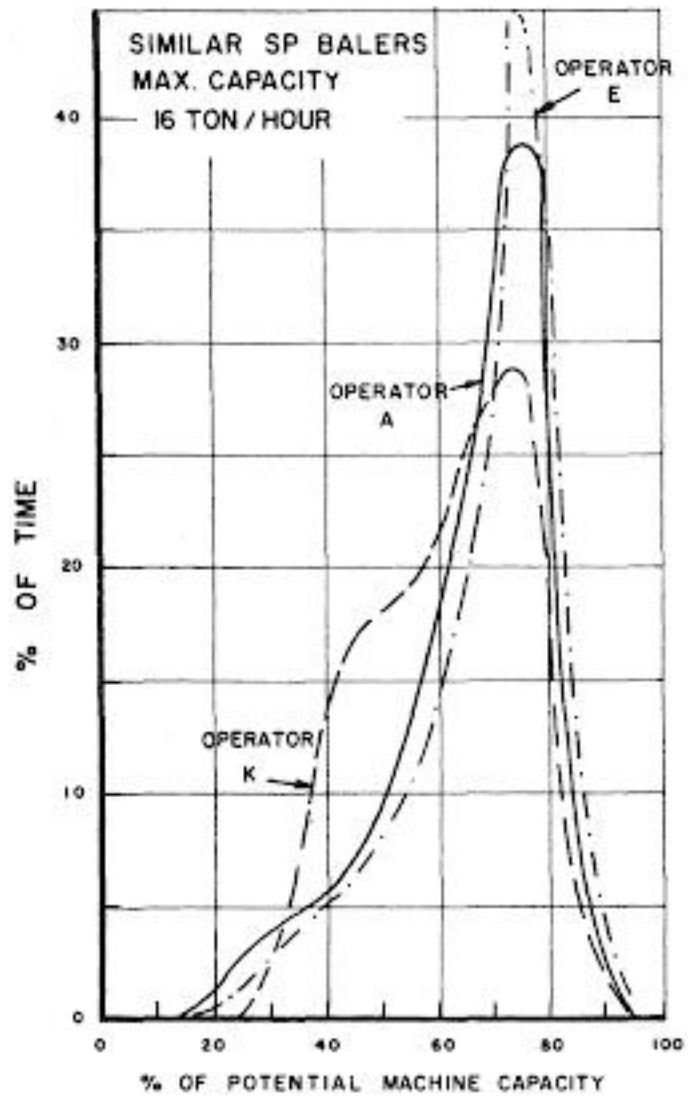


Fig. 3.4. Operator-machine performance, SP baler.

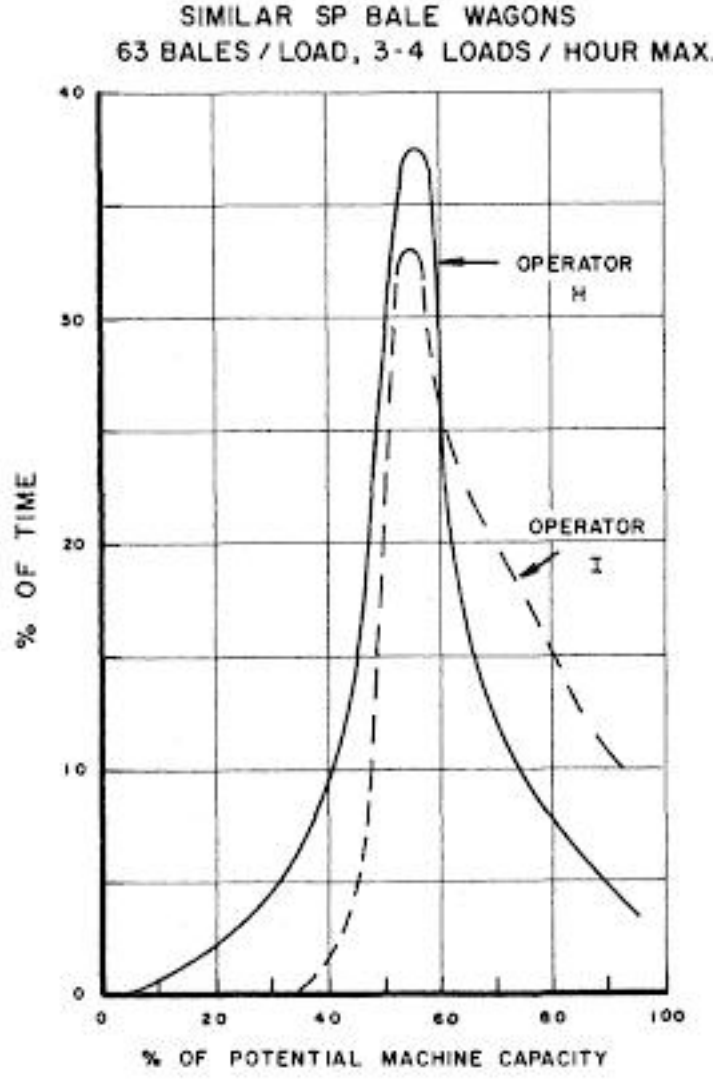


Fig. 3.5. Operator-machine performance, SP bale wagons.

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total time. As with field efficiencies in Chapter 1, time efficiencies look poor even though the actual accomplishments in acres per hour or bales per hour may be greater. The determination of an optimum field speed is one of the real challenges for the machinery manager and the machine operator.

These studies do not permit definite conclusions about the type of labor required for high-performance machines. There is no real indication that either operator age or experience gave increased performance. The factors of motivation and mental alertness are probably of greater significance but are difficult for a farm machinery manager to determine before hiring an operator.

Operator Aids for Control

Several automatic mechanical-hydraulic systems have been developed to relieve the operator of constant monitoring and control functions. Fig. 3.6 shows a mechanical sensor that acts when a trailing, row-crop harvester head is off the row enough so that the plant stalks strike the sensor. Hydraulic pressure is then triggered to actuate a cylinder between the header and the hinged tongue which automatically realigns the header on the row. With this assistance, the tractor driver is relieved of the need for precise steering.

Another example of mechanical machine control is illustrated in Fig. 3.7. The delivery spout of the forage harvester is controlled by the position of the wagon tongue relative to the harvester. When the harvester makes a turn, the spout is turned by a hydraulic motor to point to the wagon without the attention of the operator. Additionally, the motor oscillates the spout back and forth during straight-ahead operation to distribute the forage evenly in the wagon.

A combine header height system, as shown in Fig. 10.9, is an effective automatic control for harvesting low-growing, podded crops such as soybeans. The fingers gage the height of the cutterbar and through a hydraulic system raises or lowers the head to maintain a desired height above the soil surface.

There are mechanical aids that allow the steering function to be done automatically. Mechanical sensors follow a furrow, a ridge, a windrow, or a plant row and signal the steering system to make corrections. The operator disengages the system for field turns but is relived of steering for more attention to machine monitoring and control.

Instrumentation

Farm machines can have considerable instrumentation to assist the operator in making appropriate decisions and then taking proper actions. Use of instrumentation can make field operations more efficient and can be conserving of both the operator and



Fig. 3.6. Guidance control for a row crop head.

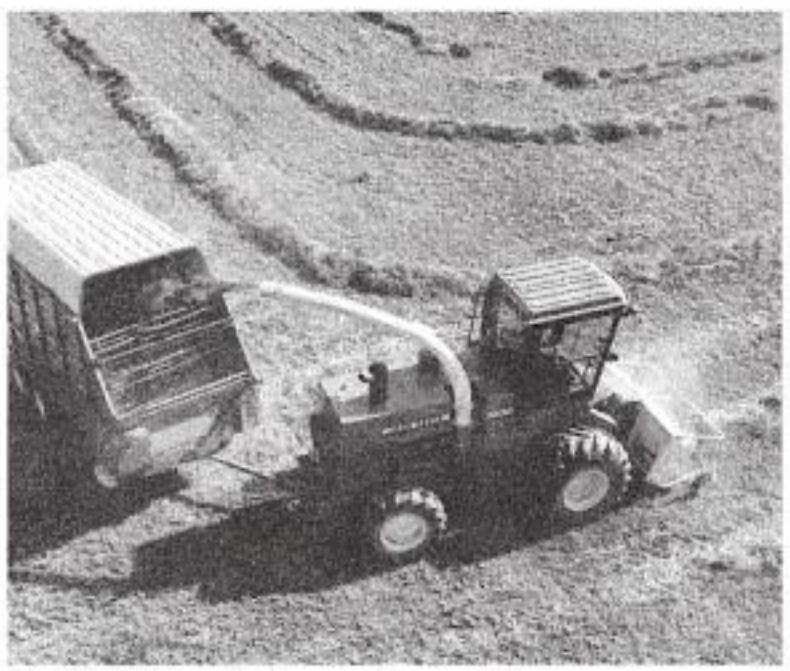


Fig. 3.7. Mechanical control for a delivery spout.

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the machine. Machinery managers and operators should understand these instrumentation systems for optimum use of the information developed, for maintenance purposes, and for determining replacement needs.

The instrumentation systems on farm machines can be grouped into three levels of technology. The first level is one of display only, sometimes called *status indicators*. Gages are mounted on an instrument panel to be monitored by the operator. Typically in the past, such gages have been analog in nature in that the relative position of a pointer sweeping across a semicircular face indicates the amount of the reading. More recently, digital instruments have replaced most analog gages. Digital instruments display a single measurement number at any instant. These digital displays are frequently larger, lighted, and provide data that are easily read. Examples of this level of instrumentation are the common engine sensing systems for coolant temperature, oil pressure, ammeter, voltmeter, engine speed, air cleaner resistance, and fuel levels. Examples of implement operation display systems are seed counters for planting machines, spray delivery, speed indicators for combine cylinders and cotton picker drums, combine cylinder-concave clearance and stone trap door position, and shape of a round bale being formed. The operator must monitor these displays and take corrective action when conditions warrant. Some systems produce a sound signal or a flashing light when an operating condition is outside an acceptable range.

A second level of instrumentation technology provides the operator with increased control over the machine functions. This level has been increasingly employed in farm machinery with the advances in solid-state electronics. Such circuitry typically converts a sensed condition into an electronic signal, displays a value to the operator, and then sends the operators electronic response to a hydraulic actuator which controls the machine adjustment. Such adjustments can be made instantly without stopping the forward progress of the machine. Variations in soil fertility and condition can occur over a very short distance of field travel. Quick adjustments to application rates of fertilizer, seed, and pesticides allows this instrumentation level to meet the demanding needs of modern precision agriculture.

Fig. 3.8 illustrates a second level monitor display for a baler. Touch panels provide control of bale density and the unloading of bales into an accumulator (refer to Fig. 11.20). The digital display indicates the bale density, the bale count and bales per time, the plunger strokes per minute and per bale, the location of the bales on the accumulator, and the forces on the plunger. Indicators advise the tractor operator to drive to the left or right over the windrow to produce a more uniform bale cross section and which of the 5 knotters missed a tie. Warning lights and a horn indicate failures of density-control hydraulic pressure, over- and underspeeds, pick-up plugs, stoppages, flywheel brake activation and nonready accumulator status.

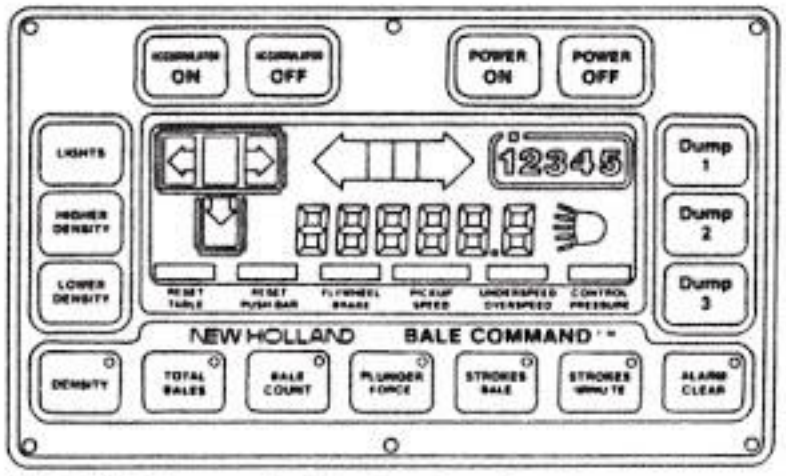


Fig. 3.8. Baler monitor in a tractor cab.

An important second-level instrument is the radar-like sensor of Fig. 3.9. This sensor measures the machine's actual ground speed as opposed to speed indicators based on wheel revolution. These data can be processed into a display of forward speed and drive-wheel slip. These data are also used to display the amount of area processed. The operator enters the effective width of the implement into the memory of the microprocessor, which combines time and the distance traveled to display an instantaneous area performance rate. When combined with the data from a chemical or seeding system, a current application rate

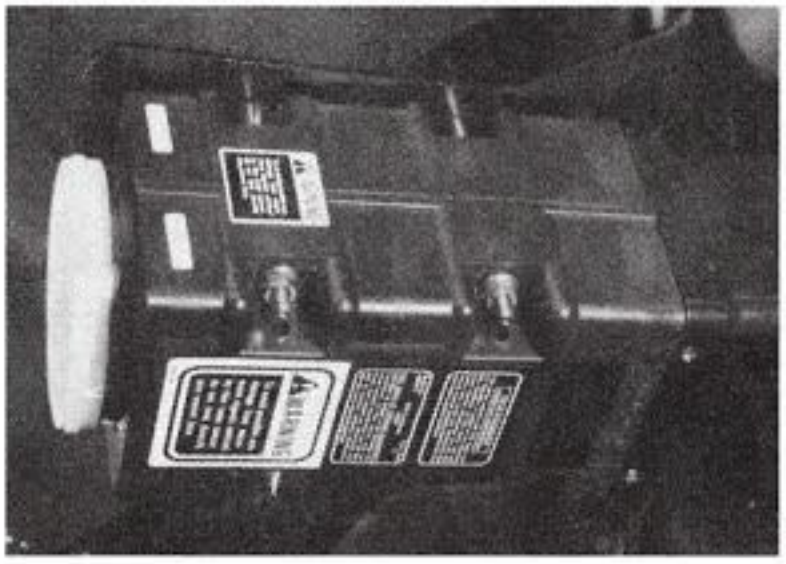


Fig. 3.9. Sensor for measuring true ground speed.

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is computed and displayed to the operator. At this level the operator is a judgment link between the sensed display and the control that can modify the machine function.

The third level of instrumentation technology senses conditions and makes adjustments to machine operations without operator involvement. Such systems can be engaged or disengaged at the discretion of the operator who is always able to take over command from such automatic systems. Global positioning systems (GPS) can be utilized to identify the position of the machine in the field, and record it in memory. Fig. 3.10 shows the necessary signal travel from the satellite to the machine. Fig. 3.11 shows the instrumentation needed to use GPS. In addition to position location this equipment monitors grain moisture and yield and area covered for combine harvesting. The equipment is portable to seeders and fertilizer applicators to provide application rate control. The parallel swathing indicator assists the operator in steering machines so that overlap and skipped strips are avoided. This feature is particularly valuable for night time operations where it is difficult to see the swath edge even if lighted. An additional correctional signal added to GPS (Differential Global Positioning System or DGPS) allows location accuracy to about one-fourth of a metre. This location can be automatically compared with a map of the field attributes stored in memory. An appropriate implement adjustment signal is then created and an adjustment made for that specific sector of the field in which the implement is operating. Yield maps are developed during harvest using GPS to relate the instantaneous yield to location in the field. These data can be recorded on cards for later reading into a computer which prints the map. Soil fertility maps are developed from a grid sampling of the field.

An eventual technology level may avoid the maps by having instantaneous sensing of soil conditions and weed and pest infestations with consequent implement



Fig. 3.11. GPS antenna, display console, and indicator for parallel swaths.

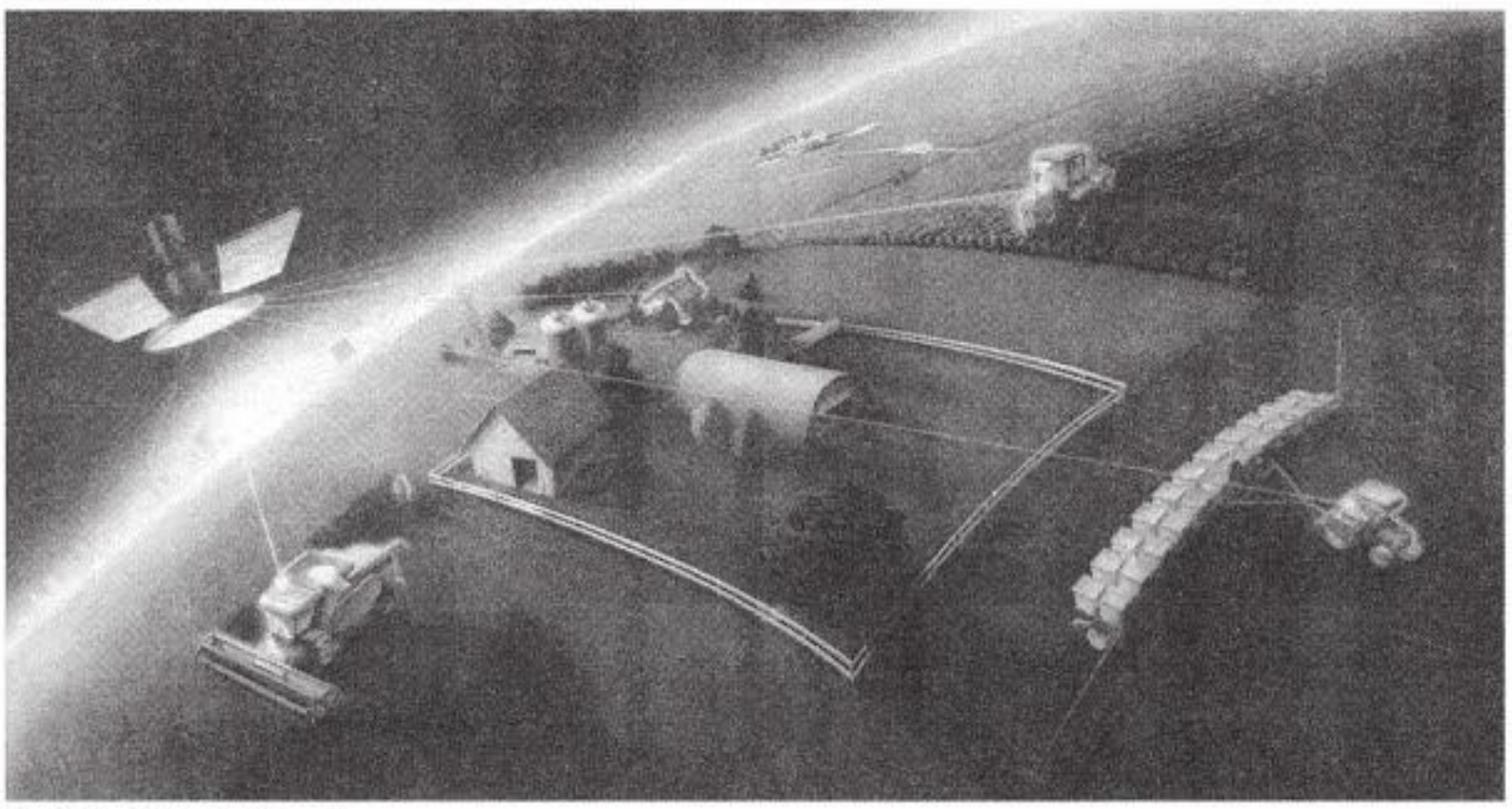


Fig. 3.10. GPS signal travel.

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ing equipment. Compliance is not mandatory if only family members operate the equipment. The equipment operation areas judged to be most hazardous have received initial attention and regulation. Additional regulations may be expected in the future.

Highlights of the present regulations pertaining to farm field equipment and operations are listed here.

Tractors

A. All tractors with 15-kW [20-HP] engines must be equipped with rollover protective structures (ROPS) and seat belts. Figure 2.10 shows a ROPS designed to meet OSHA standards. Enclosed tractor cabs must meet the same standards. Low-profile tractors and tractors mounted with equipment incompatible with ROPS are exempt, but only while the tractor is being used in operations where vertical clearance is insufficient or where mounted equipment occupies the ROPS space. After such operations are completed, the ROPS must be reinstalled.

B. The employer must instruct the employee at the time of the initial assignment to the tractor and annually thereafter as follows:

1. Securely fasten your seat belt if the tractor has ROPS.
2. Where possible, avoid operating the tractor near ditches, embankments, and holes.
   on rough, slick, or muddy surfaces.
3. Stay off slopes too steep for safe operation.
4. Watch where you are going, especially at row ends, on roads, and around trees.
5. Do not permit others to ride.
6. Operate the tractor smoothly with no jerky turns, stops, or starts.
7. Hitch only to the drawbar and hitch points recommended by the tractor manufacturer.
8. When the tractor is stopped, set brakes securely and use park lock if available.

Implements

A. All farm field and farmstead equipment, regardless of the date of manufacture, must be provided with guarding of all PTO drives. The shielding must be sturdy enough to withstand the effects of a 113-kg [250-lb] person stepping on the installed shield. When the PTO is disconnected and removed, the protruding stub shaft from the tractor shall be guarded.

All new farm machines must have guards or shielding over moving parts. These include rotating shafts; ground-drive power trains; and the pinch or nip points that occur as belts feed onto pulleys, chains feed onto sprockets and idlers, and gears and other mechanisms mesh. Even the functional parts of machines (cutter bars, reels, snapping rolls, etc.) must be shielded as much as possible and yet permit their intended function. Warning signs and motion signals are required where shields may have to be removed to get at moving parts for service and maintenance reasons.

B. At the time of the initial assignment and at least annually thereafter, the employer must instruct the employee in the safe operation and servicing of the equipment including at least the following:

1. Keep all guards in place when the machine is in operation.
2. Permit no riders on farm field equipment other than persons required for instruction or assistance in machine operations.
3. Stop engine, disconnect the power source, and wait for all machine movement to stop before servicing, adjusting, cleaning, or unclogging the equipment except where the machine must be running to be properly serviced or maintained, in which case the employer shall instruct employees as to all steps and procedures necessary to safely service or maintain the equipment.
4. Make sure everyone is clear of the machinery before starting the engine, engaging power, or operating the machine.
5. Lock out electrical power before performing maintenance or service on farmstead equipment.

Noise

OSHA has set noise limits for the environment surrounding workers. The basic permissible noise intensity is 90 decibels on the A scale of a sound level meter, 90 dB(A), at slow response for an eight-hour day. The slow response setting averages out intermittent high-level noises such as hammering. Higher levels of noise are permitted for shorter periods (Table 3.4). Exposure to various sound levels are accommodated by formula. The ratios of the actual exposure time to permissible exposure time at each sound level must sum to less than one. In effect, this formula requires that part of the day must include exposures to less than 90 dB(A) if there is any expo-

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Table 3.4. Permissible OSHA Noise Exposures

Level, dB(A)	hr/day
90	8
92	6
95	4
97	3
100	2
102	1 1/2
105	1
110	1/2
115	1/4
140	0

sure to levels above 90 dB(A). This scale is logarithmic. An increase of 10 dB(A) will approximately double the loudness to the human ear.

The machinery manager may be able to reduce the noise of farm machinery to acceptable levels; but if not, ear plugs or ear muffs must be provided and must be worn.

Anhydrous Ammonia Application

The handling of anhydrous ammonia has been considered hazardous by OSHA. Workers are required to wear impervious gloves and goggles or a face shield for protection in the case of an accidental release of ammonia. A water supply of at least 19 L [5 gal] must be available on the tank-transporting vehicle, which must have a drawbar equipped with a safety chain and which must not whip or swerve dangerously from side to side when being towed. The tank must be securely fastened to the vehicle.

For fertilizer applicator tanks of 1000 L or 1 m^3 [250 gal] capacity or less, tanks may be filled by venting to open air provided the bleeder valve orifice does not exceed 1.11 cm [7/16 in.] in diameter.

Other regulations cover the design of tanks, hoses, and valves. The responsible machinery manager will rent or purchase only equipment that meets OSHA standards and will see that this equipment is maintained.

Emblem

The slow-moving-vehicle (SMV, 40 km/hr [25 MPH]) emblem is required for all farm equipment driven on roads (Fig. 5.4). The emblem must be located in a vertical position 0.6 to 1.8 m [2 to 6 ft] above the ground and in a central position on the rear of the vehicle.

Various administrative responsibilities are required by OSHA. If ten or more workers are employed on a farm or a ranch, OSHA requires records of job-related deaths, injuries, and illnesses. A supplemental record of each incident and an annual summary are also required. All farmers with at least one employee are required to post a copy of the OSHA poster, which explains employee rights and responsibilities. A farmer must report to OSHA within 48 hr the details of a farm accident resulting in one or more deaths or the hospitalization of five or more employees. Farmers must also cooperate with surveys conducted by the Bureau of Labor Statistics. Farms and other businesses are subject to inspection by OSHA compliance officers if an employee files a complaint, if a major accident occurs, or if the farm is randomly selected for inspection.

Census statistics show that hired employees make up less than 27% of the U.S. farm labor force; thus, many farms need not comply with OSHA standards. A safety-conscious farmer, however, will comply with OSHA standards since in all probability it is family members that will be protected. Additionally, a farmer must provide for those occasions when temporary labor will operate the machines.

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Part II

Costs

Most management decisions for farm machinery involve an accurate knowledge of costs. Maintaining an accurate record of costs is an indispensable part of the machinery manager's job. The cost of maintaining and operating machinery is a deductible business expense for income tax purposes, which is sometimes the sole reason for keeping good cost records.

But such records aren't being used to their maximum extent unless these records are also used to aid in decision-making processes that are the core of good machinery management. Disappointingly, the use of cost data has to be made by estimation only since the actual cost of use of a machine is never known until the machine has been sold or worn out and junked. One can't postpone decisions until then to determine the cost of operations. The ideal situation is some running account wherein the manager can estimate closely the cost per unit of production of a particular machine for any operation and at any moment.

Representative machinery costs have been a popular subject for agricultural experiment stations. Publications on costs are available for most field machine operations in many sections of the nation. The applicability of such costs suffers from rapid changes in prices and technology and costs are often of historical interest in only a few years. In no way can it be said that there are standard costs for field operations as there are in some manufacturing industries.

The determination of the field machinery cost of operations depends on so many factors that each farm's machinery system must be treated as a special case. Significant differences in machine use, price levels, energy requirements, fuel costs, and labor costs suggest that the farm machinery manager will have to develop individual standard costs and use the average costs obtained by others only for comparison purposes.

The ultimate goal of the machinery manager is to maximize enterprise profits by getting the greatest output from machines at a minimum cost. Note again that it is the cost of use of a machinery system that is to be minimized, not the cost of use of individual implements. A long-range management viewpoint must also be maintained; that is, when the economy of a machine is being evaluated, one must keep in mind that the present machine is only one of a succession of machines whose

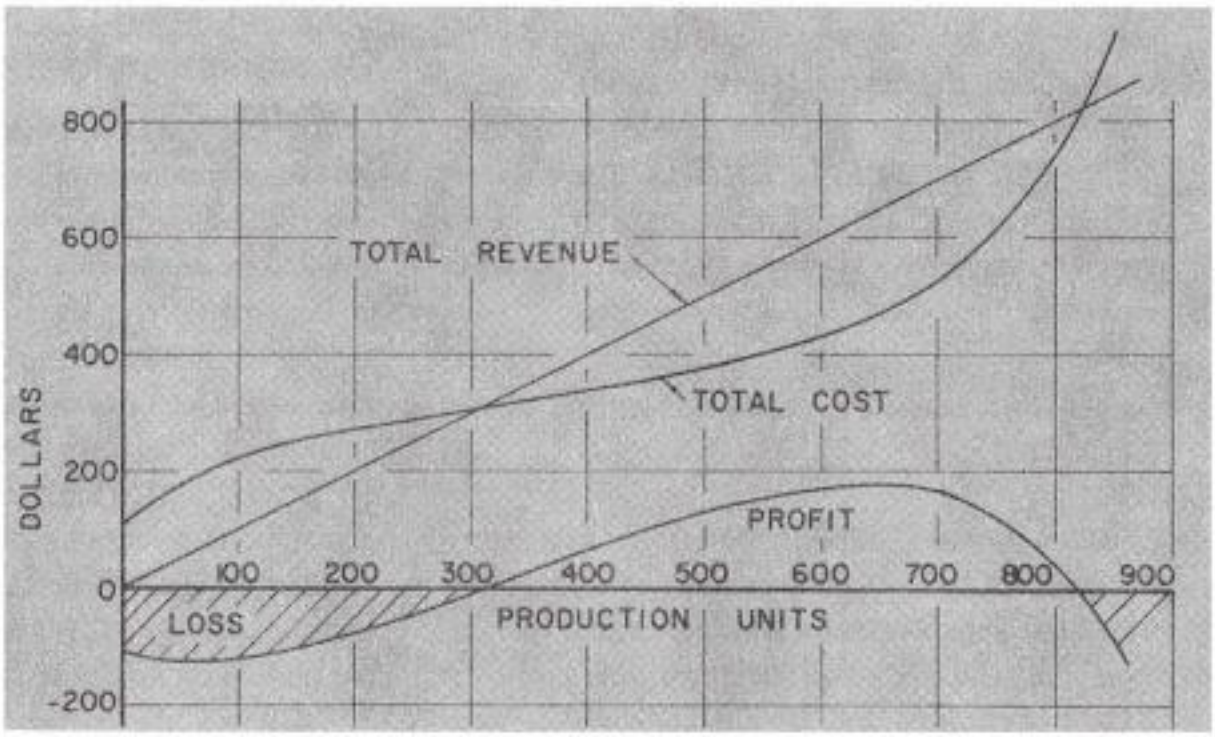
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Chapter 4

Cost Determination



As this sample graph illustrates, costs influence profit substantially. For farmers who don't have control over product prices, the revenue curve is straight and pretty well fixed; thus, profit depends wholly on the position of the cost curve. If the cost curve can be lowered, profit will begin at a lower production and reach higher values.

The size of a profitable enterprise is also defined by the graph. If the cost curve shown reflects the cost curve for machinery, then the size of an operation can be limited by machinery costs. A detailed knowledge of machinery costs is essential to a profitable farm business.

Machinery costs are divided into two categories, *fixed costs* and *variable costs*. Variable costs increase proportionally with the amount of operational use given the machine, while fixed costs are independent of use.

It is not always clear which category some of the specific costs belong in. The costs of interest on the machinery investment, taxes, housing, and insurance are dependent on calendar-year time and are clearly independent of use. The costs of fuel, lubrication, daily service and maintenance, power, and labor are clearly costs associated with use. The two remaining cost items, depreciation and the cost of repairing, seem to be functions of both use and time.

Depreciation

Depreciation, often the largest cost of farm machinery, measures the amount by which the value of a machine decreases with the passage of time whether it is used or not. The value declines because of several factors.

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1. The parts of the machine become worn with use and cannot perform effectively. These parts are the economically irreparable mechanisms in a machine; for example, the basic frame may be worn or distorted. The field capacity of the machine may decrease and/or its material performance may suffer.
2. The expense of operating the machine at its original performance increases as more power, labor, and repair costs for the same unit of output are required. Repair and adjustment can renew the machine but at an increased rate with age.
3. A new, more efficient machine or practice becomes available. When this situation develops the existing machine is said to be *obsolete*. The existing machine may be functionally adequate but because of new technology it is uneconomic to continue to operate it.
4. The size of the enterprise is changed and the existing machine's capacity is not appropriate for the new situation.

It may be inferred from this discussion that depreciation is more likely a function of time for machines having small annual use. Obsolescence and rust are likely to end the life of these machines. Only for large farm operations will the mechanical deterioration due to use likely end a machine's life.

Machine Life

Three concepts of machine life concern the machinery manager: physical life, accounting life, and economic life. The *physical life* (also called service life) is terminated when a machine can't be repaired because of an irreplaceable or irreparable part failure. Most equipment manufacturers stock repair parts for years after a model line has been discontinued and the physical life of a farm machine can be very long.

An *accounting life* is the predicted life in hours of use for a machine based on the surveyed use of existing machines and upon the design life used by the manufacturer (see Table 4.5). The predicted life in years can be estimated by dividing the wear-out life by the hours of annual use.

The *economic life* of a machine is a more pertinent measure of the time period for which depreciation should be estimated. Economic life is defined as the length of time from purchase of a machine to that point where it is more economical to replace it with a second machine than to continue with the first. At this time a machine may still have considerable service life but be uneconomic because of high rate-of-repair costs, technological obsolescence, or a change in the farm enterprise. The machine may still be retained in some lesser role as part of the machine system or it may be sold to someone for whom it will have continued economic life. In such an event the price paid by the second owner will determine the depreciation cost to the first owner.

Depreciation Methods

An *estimated value* method may be the most realistic determination of depreciation. At the end of each year the value of a machine is compared with its value at the start of the year. The difference is the amount of depreciation.

The estimated values of aged farm machines are established at farm sales, at specialized machinery auctions, and by farm equipment dealers through use of "guides" and "blue books." These publications are compiled from reports of trading practices by dealers themselves and are used as a guide for quoting trade-in allowances for aged equipment. The values are quoted on an "as is" basis.

Table 4.1 shows average yearly depreciation for farm machines as a percentage of the purchase price. The mower conditioner, cotton and forage harvester data is from published "as is" values in 1991. The remaining data were developed by T. L. Cross, University of Tennessee, and G. M. Perry, Oregon State University, 1994. Variations as much as 10% about these values can be expected, depending on the popularity of specific models. Inflation effects during the 20-year period are included. It is apparent that the greatest depreciation occurs during the first year of life. The depreciation in succeeding years declines until a constant 1% occurs. The accumulated depreciation is the sum of the individual year values. For example, the accumulated depreciation for a plow at the end of year 10 is 72% of the purchase price.

Other reports state depreciation on usage and not age. A 1999 Midwest study showed tractors depreciating at 1.35% of the purchase price, P, per 100 hours of use. Self-propelled combines depreciated at 2.54% P/100 hr.

The depreciation method used for farm equipment is of concern to the federal government, as the cost of depreciation is a deductible item for income tax purposes. The Internal Revenue Service (IRS) suggests two specific methods of calculating depreciation.

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1. *Straight-Line Method.* The annual depreciation charge using Eq. 4.1, is

$$D = (P - S)/L \tag{4.1}$$

where P = purchase price
S = salvage or selling price
L = time between buying and selling, yr.

This method is the simplest, as it charges an easily calculated, constant amount each year.

2. *Declining-Balance Method.* A uniform rate is applied each year to the remaining value (includes salvage value) of the machine at the beginning of the year. The depreciation amount is different for each year of the machine's life. Eq. 4.2 expresses the relationships by formulas.

$$D = V_n - V_{n+1}$$

$$V_n = P\left(1 - \frac{x}{L}\right)^n \quad V_{n+1} = P\left(1 - \frac{x}{L}\right)^{n+1} \tag{4.2}$$

where D = amount of depreciation charged for year n+1
n = number representing age of the machine in years at *beginning* of year in question
V = remaining value at any time
x = ratio of depreciation rate used to that of straight-line method (x may have any value between 1 and 1.5.

Table 4.2 lists depreciations as percentages of P for the year in question if one would rather not solve

TABLE 4.1. Estimated Value Annual Depreciation (% of purchase price)

	End of Year																			
Machine	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Tractors	30	6	6	5	4	4	3	3	3	2	2	2	1	1	1	1	1	1	1	1
Combines	30	12	8	6	5	4	4	3	3	2	2	2	2	2	2	1	1	1	1	1
Cotton, forage harvesters	54	5	4	3	3	3	3	3	3	2	2	2	1	1	1	1	1	1	1	1
Balers	32	7	4	4	3	3	3	2	2	1	1	1	1	1	1	1	1	1	1	1
Mowers	44	5	3	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1
Mower-conditioners	50	5	5	4	4	3	3	3	3	2	2	1	1	1	1	1	1	1	1	1
Plows	59	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Disk harrows	30	8	5	5	3	3	3	3	2	2	2	2	2	2	1	1	1	1	1	1
Planters	25	5	4	4	3	3	2	2	2	2	2	2	1	1	1	1	1	1	1	1
Manure spreaders	41	6	6	5	5	3	3	3	2	2	2	2	2	1	1	1	1	1	1	1

TABLE 4.2. Remaining Values of Machines Expressed as a Percentage of Purchase Price for Each Year of Life (10-yr life and 10% salvage value assumed for depreciation methods)

	End of Year										
Method	0	1	2	3	4	5	6	7	8	9	10
Straight-line	100	91	82	73	64	55	46	37	28	19	10
Sinking-fund[a]	100	94	88	80	72	64	55	45	34	23	10
Double-declining-balance	100	80	64	51	41	33	26	21	17	13	10
Trade-in values											
Tractors	100	64	61	57	54	51	49	46	44	42	40
Major implements	100	59	54	50	46	43	39	37	34	31	29
Minor implements	100	50	45	40	36	32	28	25	22	20	18

[a] Sinking fund is computed with 8% interest compounded annually.

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Eq. 4.2. In no case is the machine allowed to depreciate beyond the salvage value.

Other depreciation methods are allowed by the IRS as long as they are consistent and do not permit depreciation to accumulate faster than for the double-declining-balance method for the first two-thirds of the machine's life.

A method of calculating depreciation used by engineering economists is the *sinking-fund method*. This method considers the problem of depreciation as one of establishing a fund that will draw compound interest. Uniform annual payments to this fund are of such a size that by the end of the life of the machine the funds and their interest have accumulated to an amount that will purchase another equivalent machine. By formulas, the values for the sinking-fund annual payment (SFP) and the value at the end of year n are

$$\mathrm{SFP} = (\mathrm{P}-\mathrm{S})\frac{\mathrm{i}}{(1+\mathrm{i})^{\mathrm{L}}-1}$$

$$\mathrm{V_n} = (\mathrm{P}-\mathrm{S})\left[\frac{(1+\mathrm{i})^{\mathrm{L}}-(1+\mathrm{i})^{\mathrm{n}}}{(1+\mathrm{i})^{\mathrm{L}}-1}\right]+\mathrm{S} \qquad (4.3)$$

Examination of the depreciation and trade-in value curves in Fig. 4.1 indicates that this method of evaluating depreciation is the most remote from actual trade-in values, as the rate of depreciation is the greatest near the end of the machine's life. Such a depreciation schedule occurs because the time value of money is taken into account.

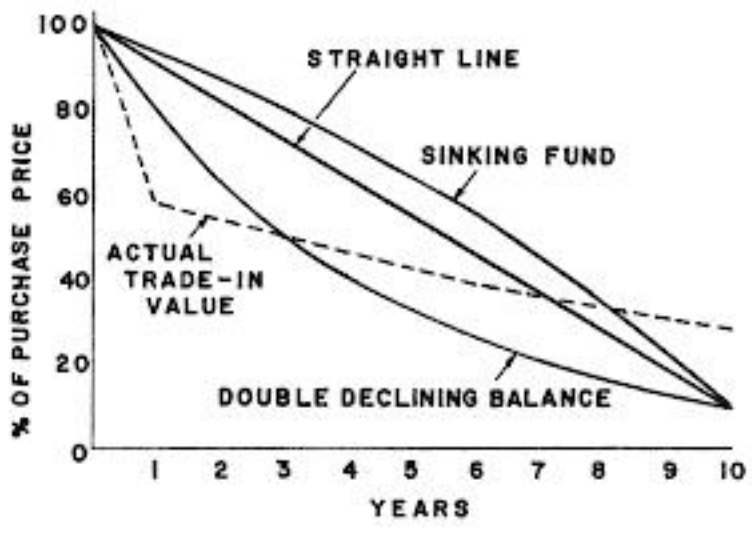


Fig. 4.1. Remaining value for three methods of depreciation compared with actual trade-in values.

The time value of money can be summarized by saying that a present dollar is worth more than a future dollar, or that delayed payments are most profitable if the money can be used to earn interest in the meantime. To illustrate, consider the worth of a present dollar invested at 10% interest compounded annually (Table 4.3). If \$5000 must be spent for new machinery in 10 years, one need deposit only \$1930.50 = \$5000/2.594 to have the amount needed.

The sinking-fund method is primarily advantageous for use with a planned replacement interval policy. It is not a very flexible program if the chance for early obsolescence is great. Very possibly the sinking-fund method most closely approximates the actual depreciation of equipment with a slow, early depreciation rate and a fast, final rate near the end of the machine's life.

Fig. 4.1 and Table 4.2 compare the various methods of depreciation with the actual trade-in values. As all depreciation methods accomplish the same thing by the tenth year, the primary difference is in the *rate* of depreciation at specific times in the machine's life.

Inflation

In times of substantial monetary inflation, a machinery manager must include the effects of inflation on machinery planning. Inflation causes increased prices for goods and services in future years. Decisions involving a time span of more than 1 year are made using values expressed in *constant dollars*, dollars from which the effect of inflation is deducted. The effect of inflation, the *inflation factor*, is equal to $(1 + i_i)^n$, where i_i is the inflation rate and n is the number of years under consideration. Table 4.3 shows the inflation factors used to obtain constant dollar values. The price of a \$1000 machine would be expected to rise to \$1000 × 1.967 (1.07^{10}) = \$1967 in 10 years; 10 years from now the price of the machine in constant dollars as of today would be \$1967/1.967 or \$1000. The price of a machine today based on constant dollars of 5 years ago is \$1000/1.403 or \$713.

Table 4.3 also shows the error that can occur in planning when inflation is ignored. A 10% interest rate might seem to be an adequate return for an investor; but when the 7% inflation rate is compounded annually and deducted from the 10% return (Table 4.3), the real return on investment is obtained. Interest rates asked by investors include any expectation of inflation. If they did not, investors could be paid

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TABLE 4.3. Value of Money (compounded)

Time	Values at 10% Interest	Inflation 7% Annually	Real Rate of Return
Today	1.000	1.000	1.000
1 yr	1.100	1.070	1.028
2 yr	1.210	1.145	1.057
3 yr	1.331	1.225	1.086
5 yr	1.611	1.403	1.148
10 yr	2.594	1.967	1.318
20 yr	6.727	3.870	1.737

back an amount worth less than the original loan. The real interest rate, i_r, is a function of the nominal interest rate, i_n, and the rate of inflation, i_i, as shown in

$$i_r = (i_n - i_i)/(1+i_i) \tag{4.4}$$

In Table 4.3, (0.10 – 0.07)/1.07 = 0.028 or 2.8%, the real return on the investment when the increase in value due to inflation is discounted.

Any time machinery planning involves a time span of several years, the effects of inflation must be discounted. The inflation factor, $(1 + i_i)^n$, allows the calculation of both constant dollar values and the real rate of return of an investment.

Fig. 4.2 shows farm equipment prices in the years after 1973. These price ratios and the expression for the inflation factor, $(1 + i_i)^n$, permit the determination of inflation rates of 5% for 1965-73, 18% for 1974-76, 9% for 1977-78, 10% for 1979-82, 3% for 1983-86, 4% for 1987-89, and 3% for 1990-91. Inflation has varied from 2 to 3% in the years following.

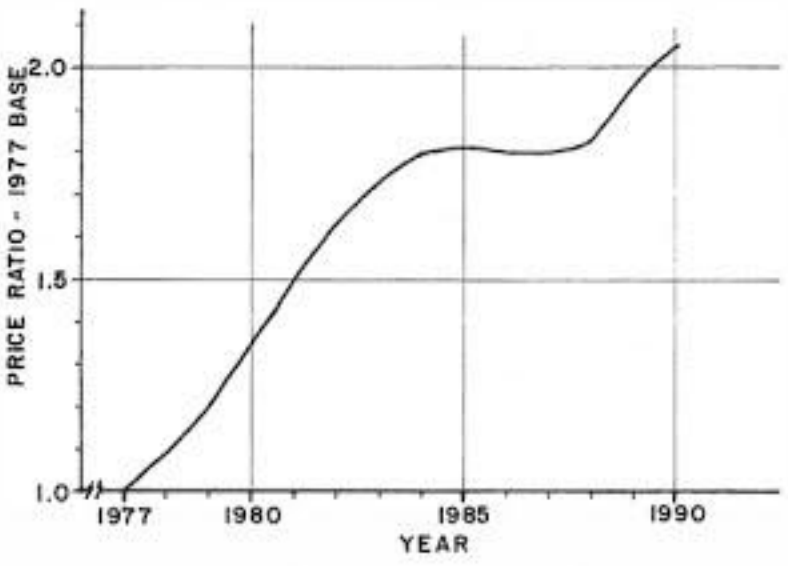


Fig. 4.2. Average inflation in machinery prices and R&M parts.

Rapid Depreciation

Depreciation has for a long time been recognized by the IRS as a cost of doing business and as such is deducted from the gross income of a business when calculating income tax. Rapid depreciation of equipment is a management accounting practice permitted by the IRS. Some machinery managers use rapid depreciation schedules to recover the investment early in a machine's life before obsolescence, accident, or wear-out ends the machine's usefulness and also to avoid income tax. Other machinery managers prefer slow depreciation schedules that spread the reduction-in-tax benefits over the actual life of the machine.

In 1998 the IRS in Section 179 permitted a farm equipment buyer to treat part or all of the purchase price as an expense rather than as a capital expenditure that must be depreciated over several years. This total expense deduction may not exceed $18,500 per taxpayer (including wife) per year. In effect this policy can provide a rapid and complete depreciation in the very first year if the price of the machine is $18,500 or less. The IRS raised the limit to $19,000 for 1999, $20,000 for 2000, and will raise it to $24,000 for 2001 and 2002, and $25,000 for 2003 and afterward.

Several limitations exist for using Section 179. The election to use this cost deduction must be made in the first year the machine is placed in service, and the deduction is allowed only to the extent that it is less than the tax bill. The allowable deduction is reduced one dollar for every dollar the price is over $200,000; that is, only $14,500 can be deducted (in 1998) for a $204,000 investment. The costs not allowed by the limits in the first year can be carried over to the second year. In no case can the deduction exceed $200,000 plus the allowable Section 179 deduction. The deduction is allowed only if the machine is used more than 50% for farming. Passenger cars, vans, and pickup trucks used 100% for farming were limited to a first year deduction of $2960 in 1994. Any deductions must reflect the proportion the machine or vehicle is used in the business.

Any Section 179 deduction must reduce the basis of that machine when depreciation is computed; that is, if a $10,000 deduction is taken on the purchase of a $100,000 combine, depreciation methods must start with the initial value (basis) of $90,000. Such a procedure models the "actual-trade-in-value" plot in Fig. 4.1.

The Modified Accelerated Cost Recovery System (MACRS) developed by the IRS is a way of securing

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rapid depreciation for equipment placed in service after 1986. Autos and trucks used in farming are counted as 5-year property, farm machinery and fence as 7-year property, grain bins and other single purpose structures 10-year property, and farm buildings are 20-year property. Allowable depreciation must be spaced over the years designated in the property class. Either straight-line or declining-balance methods of depreciation may be used.

The most rapid depreciation allowed is the 1.5 declining-balance rate for equipment placed in service after 1988 (2.0 for equipment before 1989). Any time this yearly depreciation amount falls below that for the straight-line method applied to the beginning-of-the-year value (basis) for that tax year, the straight-line amount is used. Straight-line depreciation over the whole life is acceptable but does not produce accelerated depreciation. Once the straight-line method is elected, that method must be followed during the rest of the life of the equipment.

Since 1981 the amount to be depreciated is the amount "at risk," which is effectively the purchase price. In effect, the selling or salvage value is assumed to be zero. If the machine is eventually sold for more than its depreciated value, this gain is recognized as ordinary income by the IRS. The gain is computed to be the smaller of (1) the total depreciation taken, or (2) the positive amount remaining when the depreciated value is subtracted from the selling price. If a used machine is traded in for a new machine at a dealership, the transaction is a nontaxable exchange, but the basis or undepreciated value of the new machine is the basis for the old machine added to the cash difference paid.

A convention allowing depreciation to start at midyear has been adopted by the IRS. This convention treats all machinery placed in service, or disposed of, in a tax year as if the event occurred at midyear. A half-year depreciation is allowed even though the machine was purchased in December. A midquarter convention is required if 40% or more of the total year's purchases occurred during the last 3 months.

Table 4.4 shows the IRS allowable depreciation for 5- and 7-year properties and for both types of depreciation when using the midyear convention. The declining-balance depreciations are converted over to straight-line depreciation when permissible.

Machinery managers are not required to take rapid depreciation. The IRS allows an Alternate Depreciation System (ADS), which provides for the straight-line method and the half-year convention applied to the purchase price (plus trade-in basis, if any). Property lives are 5 years for autos and light duty trucks; 10 years for farm equipment, grain bins, and fences; and 25 years for farm structures that are not single purpose.

These descriptions of depreciation practices are abstracted from the *IRS Farmer's Tax Guide*. These guidelines are offered for information only. A tax specialist should be consulted when filing a tax return.

Renting and Leasing

The possibility of renting or leasing equipment as a means of reducing operating costs is currently of interest. Payments for renting or leasing are wholly deductible from income tax as a business expense.

Renting should be distinguished from leasing. *Renting* is defined as use of equipment for small periods of time. The renting period may be terminated at any time by either party. The term *leasing* is reserved for contracts of perhaps several year's duration. The contract cannot be canceled by either party without recovery of damages.

Typical rent charges for farm machinery are expressed as percentages of purchase price for definite time periods as shown on the next page.

TABLE 4.4. IRS-Permitted Rapid Depreciation (% of the unadjusted basis)

	1.5 Declining Balance		2.0 Declining Balance		Straight Line	
Year	5 yr	7 yr	5 yr	7 yr	5 yr	7 yr
1	15.00	10.71	20.00	14.29	10.0	7.14
2	25.50	19.13	32.00	24.49	20.0	14.29
3	17.85	15.03	11.52	12.49	20.0	14.28
5	16.66	12.25	11 52	8.93	20.0	14.29
6	8.33	12.25	5.76	8.92	10.0	14.28
7	¼	12.25	¼	8.93	¼	14.29
8	¼	6.13	¼	4.46	¼	7.14

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1 day	1%
1 week	5%
1 month	15%
2 months	25%
3 months	35%

As shown later, the cost of renting farm machinery for 1 month nearly equals the fixed cost percentage used in the approximate cost analysis. Even if the lessor furnishes the necessary repair, cost of renting will surpass the cost of owning if the machine's operating season is greater than 1 month. Renting or leasing is especially advantageous to the machinery manager if there is much chance of early obsolescence.

Because several variables are involved in leasing, no absolute conclusions can be drawn as to the economy of leasing equipment. As with renting, the lease payments are deductible in the eyes of IRS; but the agreement must be a true lease and not a conditional sales contract wherein the machine is sold to the lessee for a nominal sum at the end of the leasing period.

In an appraisal of agricultural leases, W. H. M. Morris (Agricultural Economics Department, Purdue University) reached the following conclusions.

1. A lease has the objective of providing a method for obtaining the use of a piece of equipment without paying cash.
2. The risk of obsolescence falls on the lessee.
3. The possibility of borrowing money on a chattel mortgage at a relatively low rate and the liberalized income tax situation for equipment purchases typically provide a less costly alternative to a farmer than a lease on the terms usually available.
4. A lease can be a least-cost alternative for a farmer in the 20-30% income tax bracket if the return on the farmer's operating capital is 12% or more.
5. A lease is more attractive to a farmer if the machine can be purchased for a nominal sum at the end of the lease period. However, such a lease might be considered a contract sale if investigated by IRS.

Interest on Investment

The interest on investment in a farm machine is included in operational cost estimates. Even if the investment money is not actually borrowed, a charge is made since that money cannot be used for some other interest-paying enterprise. Nominal interest rates include expected inflation. The investment in a machine is greatest during the first year, as depreciation charges reclaim a portion of the investment each year.

Interest charges are usually computed when operating costs are being determined and may be calculated so that the result will be constant or an equal yearly charge throughout the life of the machine. When the straight-line method of depreciation is used, a constant annual interest charge is determined by calculating the average investment in that machine over its full life. The average investment is equal to one-half the sum of the initial value and the trade-in value. The annual interest charge will then be the product of the interest rate and the average investment.

A *capital recovery factor* (CRF) can be used to combine the total depreciation and interest charges into a series of equal annual payments at compound interest. These payments plus the interest on the undepreciated amount, S, can be used to estimate the capital consumption (CC) of farm equipment.

$$CC = (P - S)\ CRF + S\,i \tag{4.5}$$

$$\text{where } CRF = \frac{i(1+i)^{L}}{(1+i)^{L} - 1}$$

i = annual interest rate, decimal

Using typical values, L = 10 years, i = 0.10 compounded annually, S = 0.1 P, and the expected capital consumption per year would be 15.6% P. (See Table 4.7).

Property and Sales Tax

Farm machinery may be taxed at the same rate as other farm property. Wide variations exist from state to state in the amount of sales tax and in the methods of determining the assessed valuations. The property tax rate can vary widely within a state. Assuming a 4% sales tax, a property tax rate of $4/$100 evaluation, and an assessment equal to 50% value, the annual cost of taxes would be about 1.5% of the purchase price when spread over a 10-year life.

Insurance

While it is not a universal practice to insure farm machinery against loss by fire or windstorm, the insurance charge is justifiable. One who does not insure is in effect carrying the risk alone.

The rates for farm equipment are variable and fall

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between $0.30/$100 and $0.60/$100 coverage per year. Most companies will insure up to two-thirds of the value of the equipment. Assuming the average investment to be approximately one-half the original price and a rate of $0.50/$100 valuation, the annual charge for insurance would be 0.25% of the original price.

Shelter

Machinery shelter has not been shown to increase machinery life, but it can increase a machine's resale value. In a survey of dealer opinions, Neil Meador (University of Missouri) found that sheltered machinery was valued from 10-23% more at trade-in time than machinery stored outdoors. The higher percentage was for the more complex machines, such as combines used in moist, warm climates. The lower value was for tillage implements. Many farmers think that machinery shelter provides indeterminate values such as a more attractive appearance of the farmstead, easier maintenance, and easier repair.

Most farmers do provide storage for their field equipment. In a central Illinois survey, 41% of the farms had all their equipment stored in enclosed buildings and 43% had heated working space for making repairs. About 20% of the disk harrows and field cultivators were stored outside without even a protective roof.

A charge must be made against machines for shelter or paint or other deterioration prevention practices. An enclosed building dedicated to machinery storage and having a 20-year life may be expected to generate an annual charge of 12% of its purchase price. Dividing this charge by the value of the machinery stored will produce an annual storage cost for the machine of 0.5-1% of its purchase price.

Many farm machines are inexpensively sheltered in structures such as empty grain storage or unused animal shelters. The cost of shelter under these conditions is likely to be no more than 0.2% of the purchase price of the machine.

Variable Costs

Costs that vary with use, variable costs, are added to the fixed costs to arrive at the annual cost for a machine's operation. Operator labor, engine fuel and oil, and scheduled maintenance costs are associated directly with the amount of machine use. The cost of repair is not related directly to use; wear costs can be expected to occur with use, but part failures occur in a random fashion.

Variable costs may be greater than fixed costs for some high-use machines. G. E. Fairbanks, G. H. Larson, and D. Chung (Agricultural Engineering Department, Kansas State University) found the variable costs for tractors to be about 64% of all costs, with the greatest single cost being that for operator labor (Fig. 4.3). The greatest single cost of self-propelled combines was depreciation, and variable costs were only 38% of all costs.

The actual estimation of variable costs is usually based on hours of use. The cost for operator labor is the labor rate in $/hr multiplied by the expected hours of use for the machine. The fuel and oil consumption is measured or estimated from Tables 2.3 and 2.4 and multiplied by their respective prices. Any fuel tax refunds are usually considered when determining the price of gasoline. The remaining costs, repair and maintenance, are not so easily estimated. Maintenance costs include labor, lubricants, and filters used to protect the machine. While the maintenance activity is very important, its costs are relatively minor and are often included with repair as a repair and maintenance (R&M) cost.

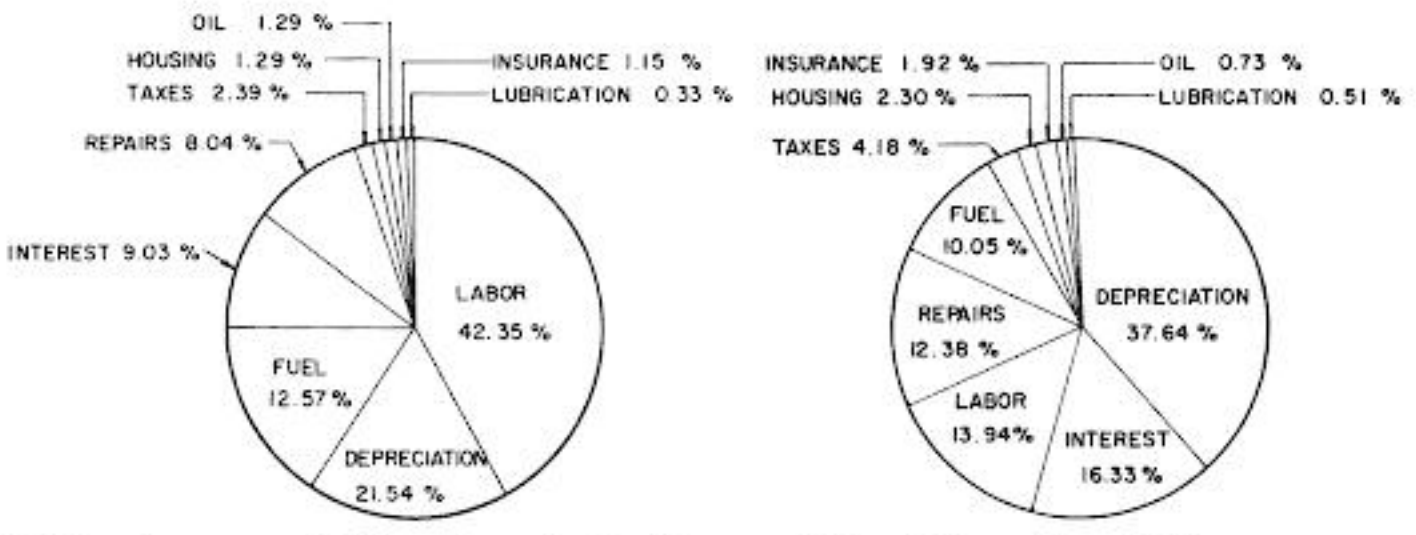


Fig. 4.3. Relative importance of all cost items for diesel tractors (left) and SP combines (right).

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Repair

Repair costs are the expenditures for parts and labor for (1) installing replacement parts after a part failure and (2) reconditioning renewable parts as a result of wear. The anticipated annual cost of repair for any one machine is highly uncertain. Plowshares, cutter bars, etc., will wear with use and will need periodic replacing at different intervals for different conditions. Many of the gears, chains, belts, and bearings, seem to fail at random. Only repair records kept on many typical machines used in actual farm operations can indicate the average or expected repair costs.

Costs incurred for replacing worn parts might be expected to approach a predictable, constant level related directly to the amount of machine use; but in fact wear is uneven because of differences in crops, soils, weather, degree of machine maintenance, adjustments, load factors, design and factory errors, etc. New machines experience about as many breakdowns as do old ones (Fig. 1.21).

Appendix E lists 1990 repair and maintenance costs for grain farms on an area-of-work basis. But the average value is not very helpful for predicting costs if the data are highly variable. The standard deviation for these data is about equivalent to the mean, which implies that 16% of the machines had a rate double that of the average while many others had zero repair.

Repair rates that reduce some of the variation can be computed. A constant repair rate of $/hr of use is popular for both tractors and implements, but it does not include any differences in machine size or accumulated usage nor account for inflation effects from one year to the next. Of particular utility because of its simplicity is the rate expressed as $/area. This rate is a good predictor for many types of implements for which repair and maintenance costs seem to be about constant per area even though the sizes of the implements vary. Inflation effects, however, make such dollar rates quickly obsolete.

A rate expressed as a percentage of a machine's list price divided by the amount of use is an effective predictor of R&M costs. Such a unit reduces variations due to machine size since large machines will have higher prices. Inflation effects are minimized if the inflation during the data gathering period represents current inflation. The machinery manager should know that the list price, and not the actual price paid, must serve as the reference price.

An R&M unit of %P/100 hr gives numerical value that are easy to use for estimating machine costs. In a presentation before the ASAE, C. A. Rotz, USDA, East Lansing, Michigan, and W. Bowers, Oklahoma State University, reviewed previous data for R&M and proposed new values for 1991 machines (Table 4.5). These values represent R&M costs averaged over the life of the machine and are not expected to predict the R&M cost for any specific year. The total R&M cost over the life of the machine is based on

TABLE 4.5. Repair and Maintenance Costs, Percentage of List Price

Machine	Wear-out life, hr	R&M, Lifetime	R&M/ 100 hr
Tractors			
2-wheel drive	12,000	100	0.83
4-wheel drive	16,000	80	0.50
Tillage			
Moldboard plow	2,000	100	5.00
Heavy-duty disk	2,000	60	3.00
Tandem disk harrow	2,000	60	3.00
Chisel plow	2,000	75	3.75
Field cultivator	2,000	70	3.50
Spring-tooth harrow	2,000	70	3.50
Roller harrow	2,000	40	2.00
Rotary hoe	2,000	60	3.00
Row crop cultivator	2,000	80	4.00
Rotary tiller	1,500	80	5.33
Seeders			
Row crop planter	1,500	75	5.00
Grain drill	1,500	75	5.00
Harvesters			
Combine	2,000	60	3.00
Combine, self-propelled	3,000	40	1.33
Forage harvester	2,500	65	2.60
Forage harvester, SP	4,000	40	1.25
Sugar beet harvester	1,500	70	6.67
Potato harvester	2,500	70	2.80
Cotton picker, stripper, SP	3,000	80	2.67
Hay Machines			
Mower, cutterbar	2,000	150	7.50
Mower, rotary	2,000	175	8.75
Mower-conditioner	2,500	80	3.20
Mower-conditioner, rotary	2,500	100	4.00
Windrower, self-propelled	3,000	55	1.83
Side-delivery rake	2,500	60	2.40
Rectangular baler	2,000	80	4.00
Large, rectangular baler	3,000	75	2.50
Large, round baler	1,500	90	6.00
Miscellaneous			
Fertilizer spreader	1,200	80	6.67
Boom sprayer	1,500	70	4.67
Orchard sprayer	2,000	60	3.00
Bean puller/windrower	2,000	60	3.00
Beet topper/stalk chopper	1,200	35	2.92
Forage blower	1,500	45	3.00
Forage wagon	2,000	50	2.50
Grain wagon	3,000	80	2.67

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the presumed wear-out life as shown in column 1. This wear-out life is the same life as the accounting life discussed previously.

As an example of the use of %R&M/100, suppose a $7000 field cultivator was used 80 hr per year. The R&M cost would be estimated as

$7000 ×.035/100 = $2.45 per hr, or $196 per yr.

A more detailed study shows that R&M costs are not constant over a machine's life but increase from a very low value during the first year to some relatively constant value after a period of use. Relationships between the rate and the hours of accumulated use were obtained from a 1967 Midwest survey of the repair costs of over 1 l00 tractors and 5000 field implements. Fig. 4.4 indicates the relationship for tractors. Little expense was reported during the first season, probably because the warranty period was in effect. The repair rate rose rapidly to a peak near the 2000-hr point of accumulated use. This point may have been the time of the first engine overhaul. A second but lesser peak occurred at 5000 hr of use, and then the rate settled to a lower and essentially constant rate.

Grain drill and baler R&M costs also show cyclic peaks (Fig. 4.5). Apparently some major repair occurs after definite intervals of use. Disk harrows and field cultivators, however, exhibited a steadily increasing R&M rate with use. Eventually one would expect these implements also to arrive at a constant repair rate related to the replacement of disk blades and shovels or sweeps.

The other machines included in this study (SP and PTO combines, corn pickers, moldboard plows, row planters and cultivators, mowers, and forage harvesters) had R&M rates that seemed completely insensitive to the amount of use. The randomness of failure seemed to outweigh any predictable effects due to wear.

Another meaningful way to consider R&M costs is to report the accumulated costs for accumulated use. The point plots of average values found for each increment of use can be fitted statistically with smooth curves having a mathematical relationship of the form.

$$Y = (c1)X + (c2)X^2 + (c3)X^3 \qquad (4.6)$$

where Y = ratio of accumulated R&M costs to list price (constant dollars)
X = units of accumulated use/1000, and
c1, c2, c3 = constants for specific machines

In a study from 1965 to 1973 of 45 Illinois corn and soybean farms averaging 215 ha [531 a] of cropland, continuous R&M histories were obtained for typical machines used for corn and soybean row crop culture. This study included only machines purchased new. The range in accumulated usage was substantially less than for the 1967 study. The more recent study covers the period of use from new up to about the point where the R&M rate becomes relatively constant. The R&M costs over this early period of a farm machine's life are significant for those who would replace machines substantially before their wear-out life.

Fig. 4.6 shows the plot, the fitted curve, and the standard deviation of Y vs. X for 79 diesel tractors averaging about 75 kW [100 HP] in size. The data points are the mean values for use increments of 200 accumulated hours. The plotted curve has a very high

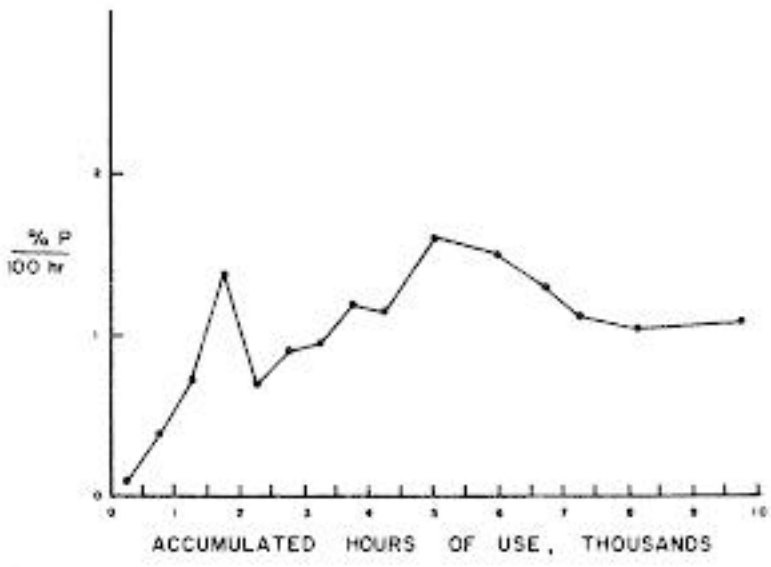


Fig. 4.4. R&M rates for tractors.

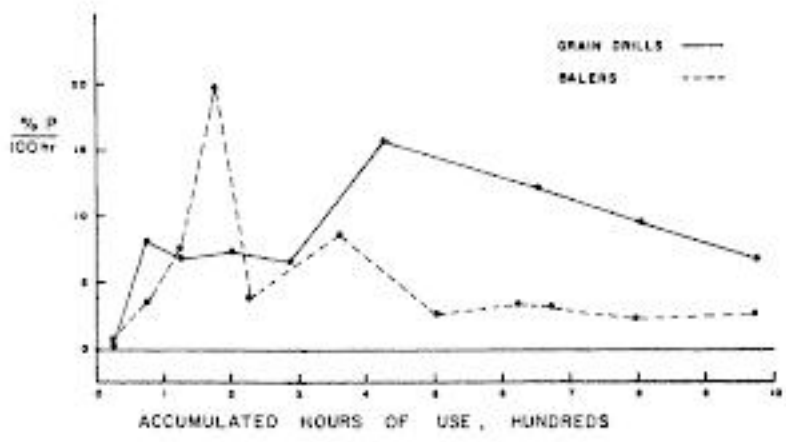


Fig. 4.5. R&M rates for balers and grain drills.

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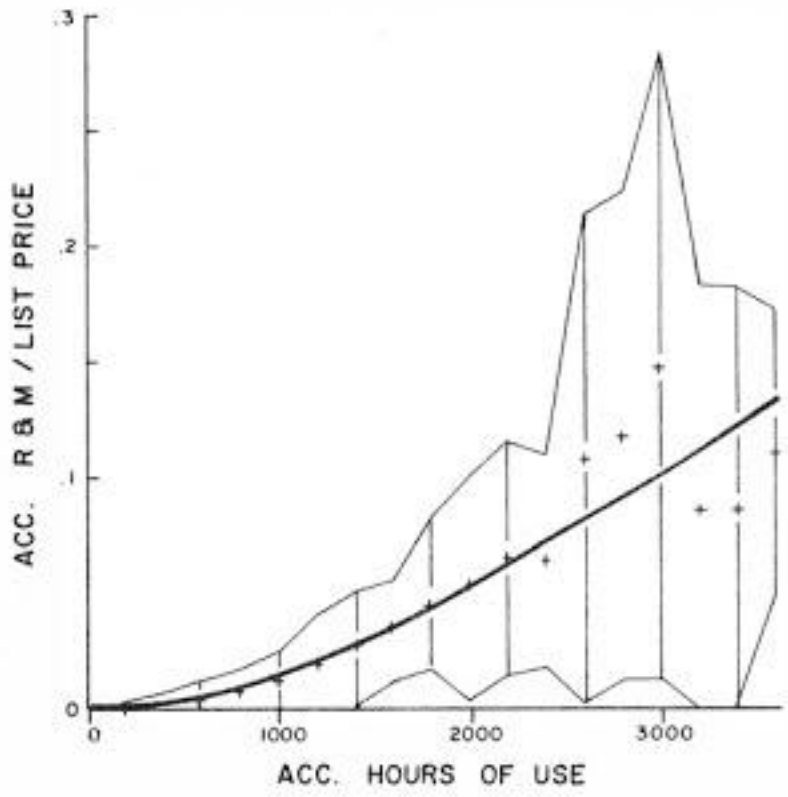


Fig. 4.6. Accumulated R&M costs for diesel tractors.

correlation with the data points and shows a linear trend at the higher levels of accumulated use. This trend is consistent with the 1967 study, which suggests a constant R&M rate after 3000 hours. The vertical lines define a standard deviation on each side of the mean and indicate highly variable data.

Table 4.6 lists the values of the coefficients (c1, c2, c3) for Eq. 4.6. The last column shows the limit in accumulated use for which Eq. 4.6 applies. These limits are expressed in units of area per unit width to place equivalent limits on both large and small machines.

Approximate Annual Costs

Estimating future costs for farm machine use is important to machinery managers. With good estimations the costs of production can be predicted, alternatives such as custom work can be evaluated, and size selection and replacement decisions can be made. The actual costs are determined at the end of each year from cost records.

Approximate costs are determined by summing expected fixed and variable costs. A machine life must be estimated to predict CC (Eq. 4.5). Capital consumption is a fixed cost that is unaffected by subsequent monetary inflation if the purchase price is considered as an investment financed over the length of life of the machine at a competitive interest rate at the time of purchase. Charges for shelter, insurance, and taxes are not so free from inflation but can be assumed as fixed costs (0.025 P) with only minor error. The variable costs per year must be added to the fixed costs to produce a complete annual cost estimate. The variable costs are most sensitive to inflation.

Eq. 4.7 expresses the approximate annual costs for a field machine in constant dollars. The two parts of the equation represent the fixed and the variable costs, respectively. Note that the term cA/(Swe) is the hours of expected use per year.

TABLE 4.6. Coefficients for Eq. 4.6 (constant dollars)

Machine	c1	c2	c3	Acc. Use Limit ha/m [a/ft]
Tillage				
chisel plows and field cultivators	0.0091 [0.0037]	0.0381 [0.005 2]	-0.0024 [-0.000 16]	360 [272]
disk harrows	-0.0017 [-0.0007]	0.0169 [0.002 8]	-0.0027 [-0.000 18]	600 [458]
moldboard plows	0.0180 [0.0073]	0.4408 [0.072 2]	-0.1452 [-0.009 62]	422 [318]
rotary hoe	-0.0198 [-0.0080]	0.1425 [0.023 3]	-0.0526 [-0.003 49]	210 [158]
row cultivator	-0.0032 [-0.0013]	0.0488 [0.008 0]	-0.0249 [-0.001 65]	385 [290]
Planting				
row planters	0.0082 [0.0033]	0.0003 [0.000 05]	0.1054 [0.006 99]	385 [290]
Harvesting				
combines, SP	-0.0035 [-0.0014]	0.0571 [0.009 4]	0.0020 [0.000 13]	460 [348]
corn pickers	-0.0148 [-0.0060]	0.3917 [0.064 2]	0.3626 [0.024 03]	250 [190]
Tractors				
diesel	-0.0042	0.019 5	-0.002 23	4000 hr
gasoline	-0.0134	0.040 3	-0.004 39	3000 hr
LP gas	-0.0003	0.009 2	0.002 26	3000 hr
Miscellaneous				
stalk chopper	0.0398 [0.0161]	0.0751 [0.012 3]	-0.0178 [-0.001 18]	230 [174]

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$$AC = \frac{(FC\%)P}{100} + \frac{cA}{Swe}[(R\ \&\ M)P + L + O + F + T] \quad (4.7)$$

where AC = annual cost of operating machine, $/yr
FC% = annual fixed cost percentage
P = purchase price of machine
c = constant, 10 [8.25]
A = annual area use in ha [a]
S = forward speed, km/hr [MPH]
w = effective width of action of machine, m [ft]
e = field efficiency, decimal
R&M = repair and maintenance costs, decimal of purchase price per hour, Table 4.5
L = labor rate, $/hr
O = oil cost, $/hr
F = fuel cost, $/hr
T = cost of tractor use by machine, $/hr (T = 0 if self-propelled)

The fixed cost percentage (FC% in Eq. 4.7) is the sum of capital consumption (CC from Eq. 4.5) and the fixed cost percentages for taxes, insurance, and shelter; which is about (2.5%) P. Values of CC are given in Table 4.7 for various years of life and at nominal interest rates with salvage or resale values equal to (10%) P in constant dollars.

With a 12% interest rate, for example, a machine that will only last 5 years and be worth 10% P at that time will have a capital consumption of 26% P for each of those 5 years. For other resale values, interest rates, and years of life, Eq. 4.5 must be solved.

The variable costs must be computed for each year if actual dollars, rather than constant dollars at age of purchase, are desired. The variable costs are bracketed in Eq. 4.7 and must be multiplied by the inflation factor $(1 + i_i)^n$ for year n after the purchase of the machine.

TABLE 4.7 Capital Consumption, CC, Percentage of Purchase Price (assumes S = 0.10 P)

Interest Rate, %	Years of Life									
	1	2	3	4	5	6	7	8	9	10
4	94	48	33	25	21	18	15	14	13	11
6	96	50	34	27	22	19	17	15	14	13
8	98	51	36	28	23	20	18	16	15	14
10	100	53	37	29	25	22	19	18	17	16
12	102	54	39	31	26	23	21	19	18	17
14	104	56	40	32	28	25	22	21	20	19
16	106	58	42	34	29	26	24	22	21	20
18	108	59	43	35	31	28	25	24	23	22
20	110	61	45	37	32	29	27	25	24	23

A typical approximate cost calculation might assume a 10-year life, a 12%-interest rate, an inflation rate of 3%, a machine purchase price of $10,000, and a resale value of (10%) P in constant dollars at the time of purchase. The approximate annual cost in actual dollars for 80 hours of use in year 5 for a $25/hr operating cost would be

$$\frac{(17 + 2.5)\times 10{,}000}{100} + 80\times 25\times 1.03^5 = \$4{,}269$$

Cost Records

Cost records of machinery operations should be kept to provide the following data:

1. Deductible expenses for income tax purposes
2. Cost of production data
3. Information on which to base equipment replacement decisions

Records in categories 1 and 2 need not be identical. Record 1 is a report to the Internal Revenue Service in which one seeks to avoid (not evade) taxes. Record 2 is used to analyze the actual costs of production. The rapid depreciation of equipment is desirable for 1 but artificial for 2. Growing a ton of corn with new equipment should not cost more than doing so with older, fully depreciated equipment; but if actual trade-in value depreciation is used (Table 4.2), that will be the case. The true equipment cost of production cannot be determined until the average costs over the economic life of the equipment are established by their replacement.

Record 3 accounts realistic and actual equipment expenses each year (see Fig. 4.7 and 4.8). Note that in a running account record of this nature the common denominator is the remaining value at the beginning of each year and not the purchase price as used in the approximate cost percentage method of calculating costs. Remaining value is determined at the end of each year (which need not be January 1 to January 1) as the difference between the remaining value at the beginning of the year and the depreciation charged for that year. Any method of depreciation can be used with this record.

The percentage charges for interest on investment, shelter, taxes, and insurance (ISTI) are not numerically comparable with the charges developed earlier in the section on approximate costs. The earlier

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MACHINE Chisel plow MFG ____ MODEL ____ SERIAL NO. ____ PURCHASE PRICE $3250

DATE PURCHASED Aug. 30 '85 AGE WHEN PURCHASED New

	1	2	3	4	5	6	7	8	9	10
END OF YEAR	1985	1986	1987	1988	1989	1990	1991			
REMAINING VALUE, RV	3000	2,200	2,400	2,100	1,900	1700	1500			
INFL.FCTR., $(1+i_1)^n$	1.03	$(1.03)^2$	$(1.03)^3$ 1.09	$(1.03)^4$ 1.09	$(1.03)^5$ 1.09	$(1.03)^6$ 1.07				
DEFL. VAL., $RV/(1+i_1)^n$	2,913	2,545	2,175	1,830	1,592	1,331				
ANNUAL COST, $/Yr										
(a) Depreciation, apparent	250	300	300	300	200	200				
(b) Depreciation, constant $	337	368	370	345	238	261				
(c) IST, (i+.055) of RV (1+.08)	155	419	372	326	295	264				
(d) Repair & Maintenance	87	112	220	135	207	242				
(e) $(c+d)/(1+i_1)^n$	235	501	537	402	421	396				
(f) Ha or (Ac) per yr.	500	550	550	620	580	437				
(g) Hours per yr. 6 acres/hr	83	92	92	103	97	73				
(h) Unit cost (a+c+d)/f or g $/acre	0.98	1.51	1.62	1.23	1.21	1.62				
REPLACEMENT ANALYSIS (in constant $)										
(i) Acc. cost, (sum b+e)	572	1441	2348	3095	3754	4411				
(j) Acc. use, (sum f or g) acres	500	1050	1,600	2,220	2,800	3237				
(k) Ave. acc. cost, i/j $/ac	1.14	1.37	1.47	1.39	1.34	1.36				
OPERATING COST, $/yr		old tractor →		new tractor →						
(l) Tractor fixed costs	3,015	2,985	4,713	4,323	4,145	2,649				
(m) Fuel & Oil	750	790	770	826	808	690				
(n) Labor @ $6/hr	498	552	552	618	582	438				
(o) Sum l, m, n/(f or g) $/acre	8.53	7.82	10.97	9.30	9.54	8.64				
TOTAL COST PER USE										
(p) h+o $/acre	9.51	9.38	12.59	10.53	10.75	10.26				

Fig. 4.7. Implement cost record.

charges were based on an average value over the life of the machine, while in the running account record they are based on remaining value. There is some question as to whether shelter charges can properly be based on remaining value, but the error if any would be small. The sum of the four percentages, I + S + T + I, may be estimated as i + 0.055 of the remaining value, RV, where i is the interest rate to be charged and the 0.055 estimates the cost of shelter, taxes, and insurance.

Since there must be one record form for each machine, the back of the form is a convenient place to record individual repair costs. These items, which include parts, maintenance costs, and repair and service labor costs, are summed each year and entered on line d.

The complete costs for an implement (Fig. 4.7) cannot be fully determined until the tractor record (Fig. 4.8) has been completed. The tractor's role in a machinery system is to provide service to implements; thus its costs must be recharged to the implements. Quite often this charge is the greatest single cost of operating an implement as shown in Fig. 4.7, where a new tractor (Fig. 4.8) was purchased in 1987 to power the plow. A common method of apportioning the tractor costs is to divide them according to the time spent with each implement. For example, the fixed and R&M costs of the tractor in 1987 were $19,516 (10,000 + 9300 + 216), and the tractor was used a total of 381 hours (Fig. 4.8). The cost per hour is shown in (h) to be $51.22. This value is multiplied by the hours of use for the chisel plow, 92 (g, Fig. 4.7), to get the $4713 value in (ℓ) for 1987. The machinery manager *must* record the hour meter readings at the start and finish of each machine operation to accurately assign tractor fixed costs to implement operations.

Fuel and oil costs should be determined from actual pump records. Lacking good records, estimated consumptions may be determined from Tables 2.3 and 2.4. It is helpful to charge the cost of the tractor's fuel

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MACHINE Tractor MFG _____ MODEL ___ SERIAL NO. _____ PURCHASE PRICE $ 70,000

DATE PURCHASED March '87 AGE WHEN PURCHASED New

	1	2	3	4	5	6	7	8	9	10
END OF YEAR	1987	1988	1989	1990	1991					
REMAINING VALUE, RV	40,000	51,000	43,000	36,800	30,000					
INFL. FCTR., $(1+i_1)^n$	1.04	(1.04)(1.07)	$1.04(1.07)^2$	$1.04(1.07)^2(1.08$						
DEFL. VAL., $RV/(1+i_1)^n$	57,692	45,830	36,113	27,995						
ANNUAL COST, $ / yr										
(a) Depreciation, apparent	10,000	9,000	8,000	7000						
(b) Depreciation, constant $	12,308	11,862	9717	8118						
(c) IST, (i+.055) of RV (1+ 10%)	9300	7905	6,645	5580						
(d) Repair & Maintenance	216	305	290	482						
(e) (c+d)/$(1+i_1)^n$	9,150	7378	5,841	4,714						
(f) Ha or Ac per yr										
(g) Hours per year	381	410	350	360						
(h) Unit cost (a+c+d)/f or g $/hr	51.22	41.98	42.73	36.28						
REPLACEMENT ANALYSIS (IN CONSTANT $)										
(i) Acc. cost, (sum b+e)	21,458	40,498	54,256	69,088						
(j) Acc. use, (sum f or g) hr	381	791	1141	1501						
(k) Ave. acc. cost, i/j $/hr	56.32	51.45	49.30	46.03						
OPERATING COST, $ / yr										
(ℓ) Tractor fixed costs										
(m) Fuel & Oil										
(n) Labor										
(o) Sum ℓ, m, n/(f or g)										
TOTAL COST PER USE										
(p) h+o										

Fig. 4.8. Tractor cost record.

and oil consumption directly to the implement. When the cost record form is used for tractors, (ℓ), (m), (n), and (o) can be omitted as these calculations are seldom needed.

The labor charge is determined from the hourly rate for one worker. Operation of two implements in tandem behind one tractor means that each implement will assume one-half the cost of labor. In such a situation the two implements should share equally the tractor's fixed costs but should divide the fuel and oil consumption according to their respective power requirements.

The total costs of operation for an implement can be displayed and analyzed with running cost accounting sheets such as those in Fig. 4.7 and 4.8. The unit costs, line h, are the costs per acre of annual use, f, for depreciation, interest on the value of the machine for a year, shelter, insurance, taxes, and repair and maintenance. The operating costs that accumulate with time can be presented as costs per unit area. For 1987 in Fig. 4.7, the sum of tractor fixed costs, fuel and oil costs, and labor costs is $6035. When divided by the annual acres of use, 550, a cost of $ 10.97 per acre is obtained and reported on line o. This amount added to the $1.62 on line h produces a total cost of $12.59/acre on line p. This cost for chisel plowing serves the farm manager when making production decisions.

These cost sheets are versatile. They can be used equally well for new or used equipment. If a tractor is replaced, the effects are incorporated without problems in Fig. 4.7. A self-propelled implement's costs are recorded effectively on such a sheet but would not use line ℓ, tractor fixed costs. The effects of inflation can be traced on this sheet but do not enter into determination of annual costs.

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Replacement

Since mechanization of agriculture is nearly complete in the United States, the purchase of new machines results from a need to replace older, inadequate machines. This replacement decision is one of the most important decisions a machinery manager must make. Replacement of a machine is indicated when

1. Accidents have damaged the implement beyond repair,
2. Field capacity of the machine is inadequate because of an increase in the scope of the operation,
3. A new machine or farm practice makes the old machine obsolete,
4. Performance of a new machine is significantly superior, or
5. Anticipated costs for operating the old machine exceed those for a replacement machine.

Estimations of yearly costs are adequate for determining crop production costs and for deciding if machine ownership is profitable; but the *time of replacement* decision depends on the *accumulated* costs over a period of years. Fig. 4.9 compares yearly costs and accumulated costs during the life of a machine. The first year's costs are high because of the very real marketplace depreciation obtained from the estimated value method. The yearly costs drop to their lowest value and then begin to rise if the annual repair costs increase with age. The accumulated cost curve drops more gradually and levels out at the point where it crosses the yearly cost curve. The *optimum replacement time* is at the crossing point since the accumulated cost curve is at a minimum and is expected to rise after that point. The costs in Fig. 4.9 need to include only depreciation, ISTI, and repair as all other costs are assumed to be independent of the time of replacement.

Machine repair rates really determine the time of replacement. Fig. 4.10 traces the accumulated cost-time histories for machines having repair rates constant with use and for those having rates increasing with use. When repairs (and maintenance) are exactly proportional to use, as in the case for replacement sweeps and shovels for tillage implements, the implement should never be replaced for economic reasons since its accumulated cost per area gets lower each year of life. But when the repair rate increases with age or use, the accumulated cost per area does reach a definite minimum point.

The smooth curves in Fig. 4.9 and 4.10 might represent the averages for many machines, but the cost-time history curve for a specific machine is likely to be erratic. Since replacement decisions are usually made on individual machines, the good machinery manager will need to keep a cost record for each machine.

The cost records of Fig. 4.7 and 4.8 can indicate to a machinery manager the optimum time for replacement of a machine. As the replacement decision involves a time span of several years, it is necessary to calculate costs in constant dollars to avoid distortions caused by inflation. The rate of inflation must be known for each year of the time period to convert the

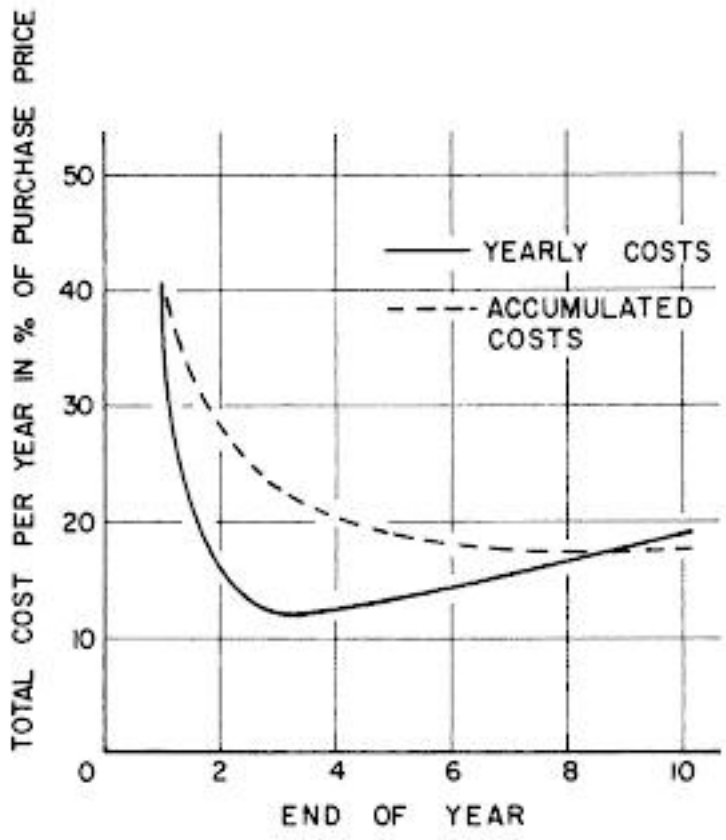


Fig. 4.9. Time of replacement: when yearly costs equal accumulated costs.

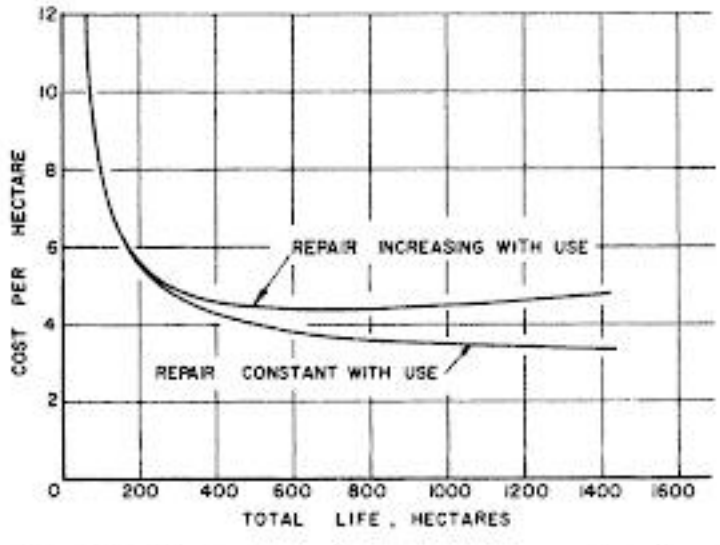


Fig. 4.10. Effect of repair costs on accumulated costs.

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The PTO-driven rate application implements are not affected by changes in speed *within* each forward gear of the tractor, but are definitely affected by changes in the *selection* of forward gears. The application rate of this type is varied by changing either the forward gear selected or the driving gear ratio of the seeder.

The constant delivery applicator (such as a sprayer) is the most sensitive to speed variation. Any slight change in the forward speed of the implement causes a change in the rate of material applied. In this type, the rate is varied by forward speed or by changing the concentration of the material applied.

It is much more important to calibrate the last two types than the first.



Fig. 8.1. A mounted grain drill.

Small-Grain Seeding Machines

Cereal grains, such as wheat, oats, rye, barley, rice, may be seeded by three types of machines.

Drills are seeders that open furrows spaced from 10-30 cm [4-12 in.], meter the seed into the furrow, and firm soil around the deposited seed in one operation (Fig. 8.1). Each seeded row is produced by a separate metering device, furrow opener, and closing mechanism.

Plain drills have only a seeding capability. *Combination drills* (Fig. 8.13) are equipped to distribute both seed and fertilizer. The grass and legume seeding attachment in the figure can be carried by either drill.

Air drills (photo at beginning of chapter) have a large central seed supply and metering device. The seed is delivered to a separate tillage tooling by air flow through individual hoses to each opener.

Field distributors are machines that consist of a seed box with metering devices in the bottom of the hopper. These implements in no way prepare a furrow for the seed. They may be used for fertilizer as well as seed. Compared to drills, these machines are inexpensive to purchase, have higher effective field capacities, and are not affected by field conditions. Unlike drilling, however, a separate seed covering operation is required. A typical field distributor is shown in Fig. 8.2.

Broadcasters are machines that meter materials onto a revolving flanged wheel (Fig. 8.3 and 9.11). This type of seeder is the least expensive to purchase. It has the highest work capacity but is the hardest to calibrate because of uneven distribution from the flanged wheels, unequal seed weight and shape, and difficulties with wind and uneven soil surface. As a seeder this machine must be followed by a seed covering operation.

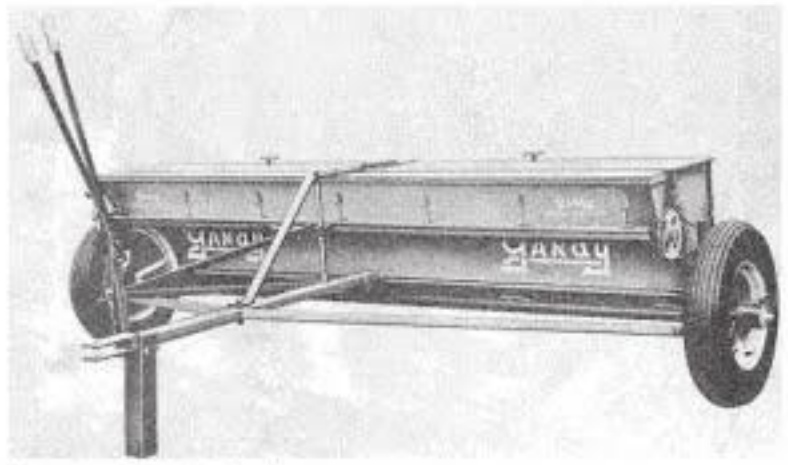


Fig. 8.2. Field distributor.



Fig. 8.3. Tractor-mounted broadcaster applying fertilizer.

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Metering Mechanisms

The seed rate controlling mechanisms are volume-metering mechanisms that may be divided into three general types.

Fluted Feed

This universal type of metering device has a delivery system that is varied by changing the drive gear ratio and by exposing different lengths of the rotor to the seed hopper. A positive-type feed, this mechanism is well adapted for use with light and irregular seeds. The lever shown in Fig. 8.4 adjusts the seed gate for different sizes of seed. Seeds as large as corn and beans can be metered by this device.

Internal Run

The smooth, internal-lipped rotor varies its delivery by changing a gear ratio, by using reducers or inserts, or by sliding the rim to greater or less contact with the seed. The internal run feed is noted for its gentle selection of the seed and for even-flow delivery (Fig. 8.5). The seeding rate is changed by sliding the drive shaft through the meter to change the exposure of the wheel to the seed supply. Changing the speed ratio between the drive shaft and the ground drive wheel also changes the seeding rate.

Variable Orifice

This simplest and oldest type of metering mechanism is used primarily on the more inexpensive field distributors. The rate of application is controlled by increasing or decreasing an aperture below the agitator in a grain box. While this type of metering device appears to be rather unreliable, it works well *if properly calibrated* (Fig. 8.6).

Air seeding is accomplished by a fluted roller placing seed (and/or fertilizer) into an air stream. Fig. 8.7 indicates the flow of seed around the roller. Air enters from above, picks up the seed, and delivers the seed through tubes to the furrow opener.

All of these metering devices work best when the seed is dry, uniform, and clean and if a mechanical agitator is used in the seed box.

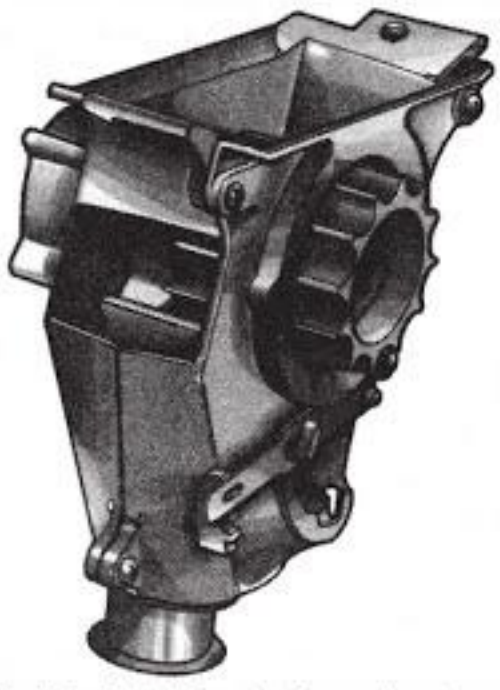


Fig. 8.4. Fluted feed with seed gate.

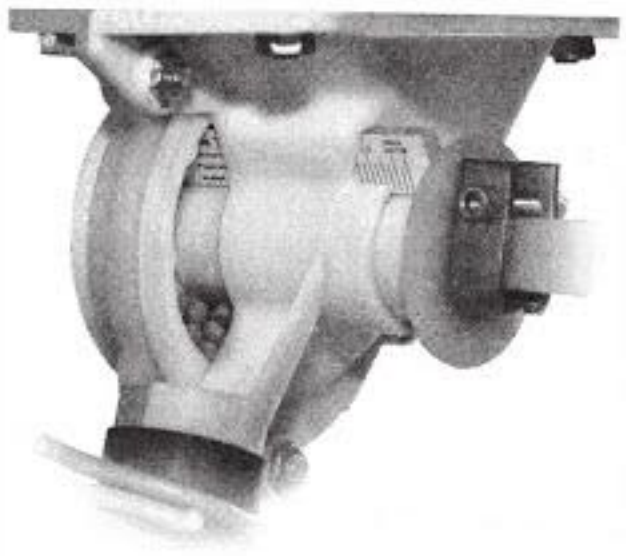


Fig. 8.5. Internal run metering mechanism.

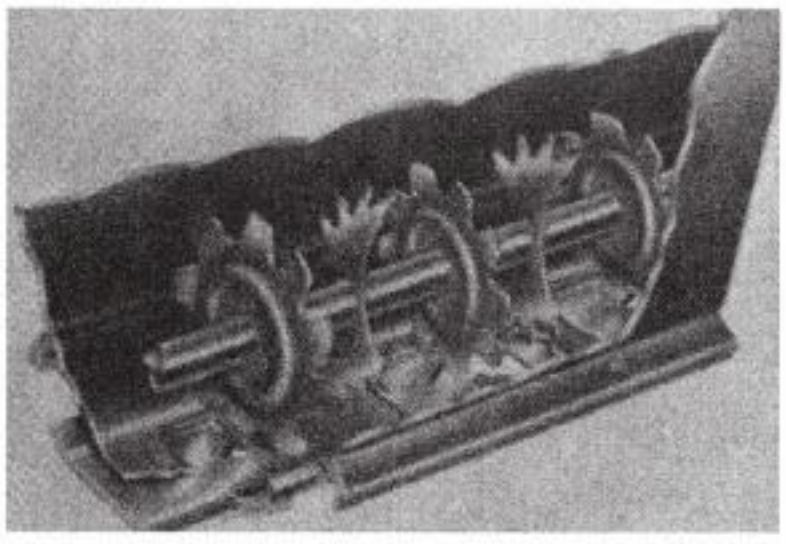


Fig. 8.6. Variable orifice agitator metering device.

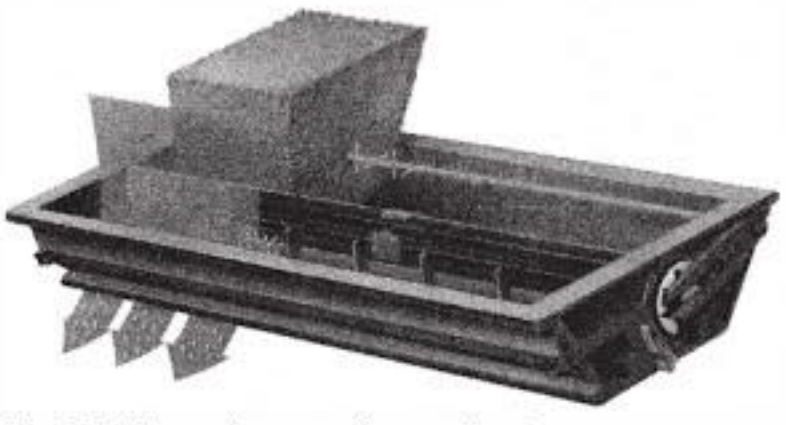


Fig. 8.7. Air seeding metering mechanism.

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Furrow Openers-Small Grain

Several different types of furrow openers are available on grain drills to meet the many varying seeding conditions.

Single Disk

This mechanism permits good soil penetration and excellent trash clearance (see Fig. 8.13 and 8.20). A particular type is the *deep-furrow opener* used on drills in the drier areas of the United States. In this case, the seed must be planted deep to find moisture, and the resulting ridges assist both in soil and water conservation and in protection for the young plants from winds.

Double Disk

A double disk gives a uniform depth of placement to the seed in soil that is well worked (Fig. 8.8).

Hoe Opener

Used in minimum tillage operations where good penetration is required, Fig. 8.9 is a hoe opener for both seed and fertilizer. Some special openers have been developed for air seeders. Fig. 8.10 shows a sweep tooling which gives a spread of fertilizer and seed. Fig. 8.11 shows an opener that produces a separation of seed and fertilizer. Additionally, it can cut through residues and thus avoid an accumulation of residues that may wrap around hoe openers.

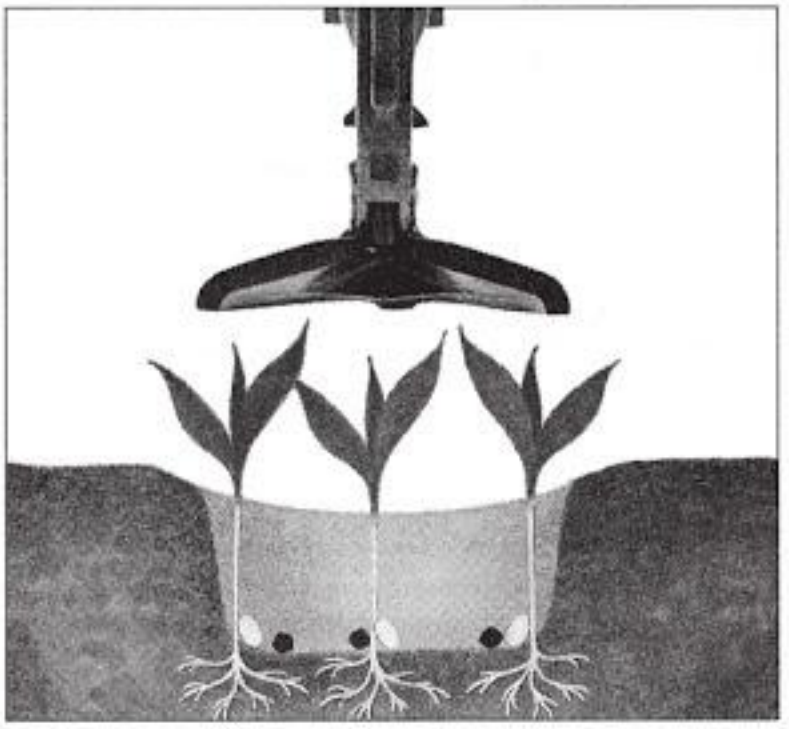


Fig. 8.10. Sweep opener seeding pattern.

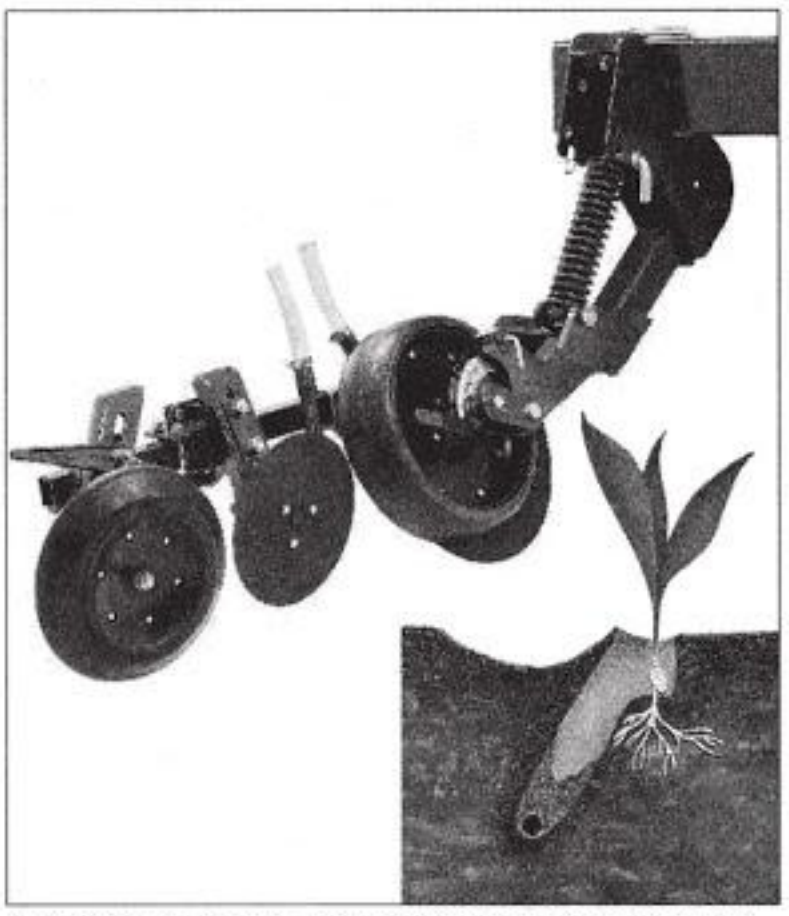


Fig. 8.11. Slant opener to give seed and fertilizer separation.



Fig. 8.8. Double disk furrow opener.



Fig. 8.9. Hoe opener seeding pattern.

Corrugated Roller

Used primarily for legume and grass seeding, seeders using corrugated rollers for furrow openers are commonly called *packer-seeders* (Fig. 8.12). This opener is particularly effective when shallow depth and a firm

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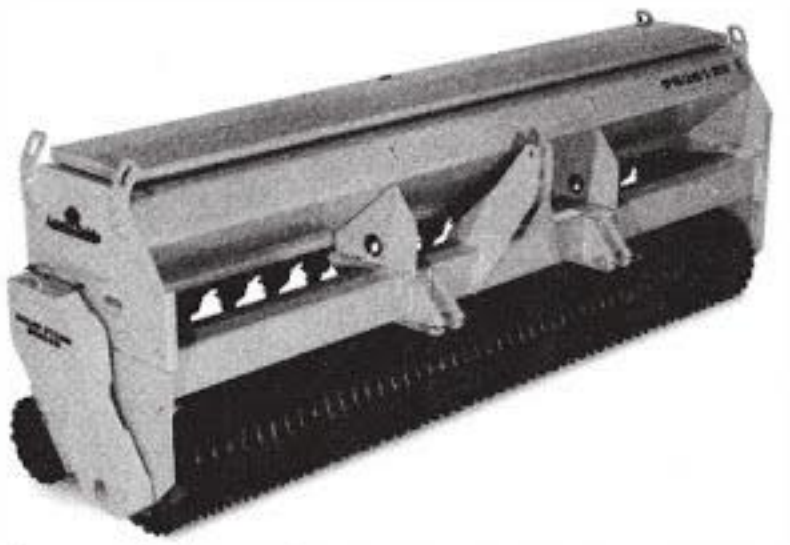


Fig. 8.12. Packer seeder.

seedbed are desired after clean tillage. This opener is very effective for seeding grasses and legumes.

Furrow openers are often arranged in staggered order to allow surface residues to pass through more easily. The need for planting into conservation tillage seedbeds requires additional tooling over that for conventional seedbeds. Additional coulters are most often used to penetrate untilled soil and to cut through crop residues left on the soil surface. *No-till* or *conservation drills* are designed to be sturdy and heavier than conventional drills. The extra weight is used to help penetrate unworked soils and those having a substantial residue cover. Kushwaha, Vaishnav, and Zoerb, Agricultural Engineering Department, University of Saskatchewan, determined the performance of coulters in a straw-covered soil bin (Table 8.1). The 46 cm [18 in.] diameter coulter appears to be an optimum size for a 55 mm [2 in.] penetration. The larger diameter requires greater down force, while the smaller was less effective in cutting the straw. The last column of Table 8.1 indicates the increase in forces when cutting through straw over that for operating in bare soil.

Soil bin work by J. E. Morrison, J. G. Hendrick, and R. L. Shafer, USDA-ARS, reported the draft of a 41-cm [16-in.] diameter coulter in bare soil was essentially independent of speed in a sandy loam soil but had an increase in draft per depth of 0.22 KN/cm [128 lb/in.].

Covering Devices

The last process of the seeding operation is that of placing and firming soil around the seed. The machinery manager adjusts the covering device to produce a deeper soil cover for large seeds and for dry soil conditions. A firm soil is needed to ensure moisture transfer to the seed but the covering process should not create soil compaction or soil crusting.

Press wheels are used to firm the soil over the planted seed and eliminate air pockets in the seedbed. They may be made entirely of steel but are usually covered with flexible rubber which can flip-off any soil accumulations. Small-diameter, narrow, press wheels can be used to firm the seed in the furrow (Fig. 8.13). Wider, larger-diameter wheels firm a wider band. A popular design uses a press wheel as a gage wheel for the opener to produce an accurate control over the depth of the opener. Such designs are common in row planters.

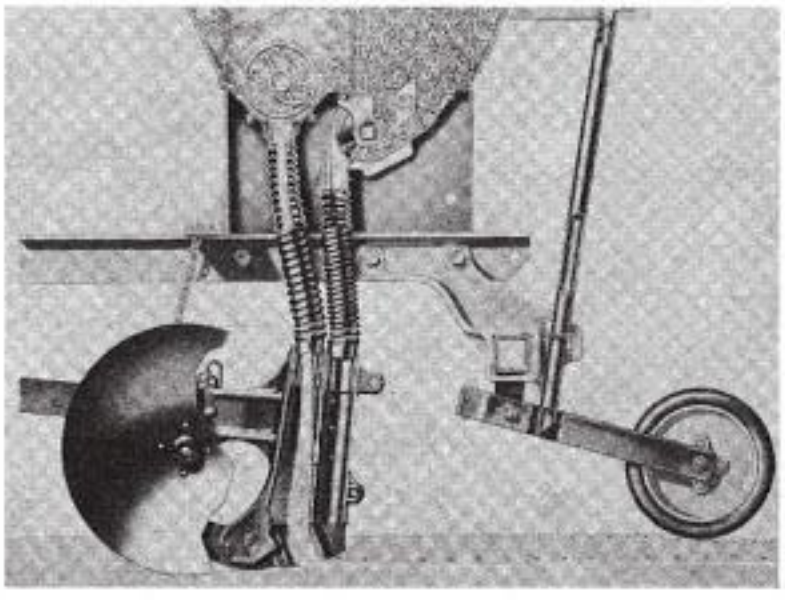


Fig. 8.13. Fertilizer drill with grass and legume seeding attachment having single disk openers and press wheels.

TABLE 8.1. Coulter Performance with Various Straw Residue Densities; Percentage Straw Residue Cut at 55-mm [2-in.] Depth

Coulter Diameter cm [in.]	Residue rates, kg/ha				Range of Increased Force, N [lb]	
	1000	2000	3000	4000	Vertical	Horizontal
36 [14]	86	60	30	17	30-160 [7-36]	45-90 [10-70]
46 [18]	100	100	99	98	35-200 [8-45]	30-100 [7-22]
60 [24]	100	100	40	30	190-300 [43-67]	30-130 [7-30]

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Chapter 17

POWER SELECTION



Selecting the proper power level for a farm is a most involved problem; yet, because the cost of power is a significant item in many operations some logical procedure must be found.

If all implements were self-propelled the analysis would be much easier, but in reality most implements are powered by tractors. Economic production is obtained by using an interchangeable power unit—the tractor. As these tractors are used with many implements, one is forced to examine the problem from a cost-of-the-whole-system viewpoint. As in the selection of individual field implements, the criterion for tractor selection is an economic one. The capacity or size of the power unit must be matched with the amount of work to be done as dictated by timeliness and cost.

As in the implement selection problem, the amount of use is most important. Area covered is an adequate statement of use for implements, but *total energy requirement* is thought to be the proper expression for tractor use. Unfortunately, the amount of power and the amount of energy required for performing various farm tasks are neither precise nor constant.

Several inherent "slack" factors will permit the use of average estimates of energy. The load factor used for designating usable power, the fact that the tractor can

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More specifically, the annual cost for tractor power is expressed as the sum of the fixed costs and the total labor and timeliness costs for each of the three types of farm jobs—field work, transport work, and processing work:

$$\begin{aligned}AC = {} & (FC\%)\,P/100 + \text{hr field work}\,(L + \text{timeliness}) \\ & + \text{hr transport work}\,(L) + \text{hr processing work}\,(L)\end{aligned}$$

Probably there should be a timeliness charge for both the transport work and the processing work, but for simplicity it will be assumed that these do not limit field operations.

The annual cost equation must be written in terms of the tractor size variable, pwr, and then minimized by the techniques in Appendix B. The purchase price, P, is replaced by t pwr, where t is the price of the tractor per maximum PTOP.

The annual hours of work required for each class of tractor operation are given by Eq. 17.1, 17.2, and 17.3

$$\frac{\text{field hr}}{\text{yr}} = \frac{\text{A ha}}{\text{yr}} \times \frac{\text{E kW}\cdot\text{hr}}{\text{ha}} \times \frac{1}{r_1(\text{pwr})\,\text{kW}}$$

$$\left[\frac{\text{field hr}}{\text{yr}} = \frac{\text{A a}}{\text{yr}} \times \frac{\text{E HP}\cdot\text{hr}}{\text{a}} \times \frac{1}{r_1(\text{pwr})\,\text{HP}}\right] \qquad (17.1)$$

$$\frac{\text{transport hr}}{\text{yr}} = \frac{0.27\text{kW}\cdot\text{hr}}{\text{t}\cdot\text{km}} \times \frac{\text{W t}}{\text{yr}} \times \frac{1}{r_2(\text{pwr})\,\text{kW}} \times \frac{\text{D km}}{1}$$

$$\left[\frac{\text{transport hr}}{\text{yr}} = \frac{0.53\text{HP}\cdot\text{hr}}{\text{T}\cdot\text{mi}} \times \frac{\text{W T}}{\text{yr}} \times \frac{1}{r_2(\text{pwr})\,\text{HP}} \times \frac{\text{D mi}}{1}\right] \qquad (17.2)$$

$$\frac{\text{processing hr}}{\text{yr}} = \frac{\text{G kW}\cdot\text{hr}}{\text{t}} \times \frac{1}{r_3(\text{pwr})\,\text{kW}}$$

$$\left[\frac{\text{processing hr}}{\text{yr}} = \frac{\text{G HP}\cdot\text{hr}}{\text{T}} \times \frac{\text{WT}}{\text{yr}} \times \frac{1}{r_3(\text{pwr})\,\text{HP}}\right] \qquad (17.3)$$

where r_i is a typical ratio of tractor output power to PTOP. The r_1 and r_2 values for drawbar loads can be estimated from Fig. 2.11. For strictly PTO loads in processing jobs, $r_3 = 1.0$.

The annual cost for tractor power in terms of the power level, pwr, is given by Eq. 17.4, which sums the hours of work required for each tractor operation and multiplies by the cost per hour:

$$AC = \frac{(FC\%)\,t}{100}(\text{pwr}) + \sum\left\{\frac{A_i E_i}{r_i(\text{pwr})}\left(L_i \frac{K_i Y_i V_i A_i}{(sc)_i (nt)_i U_i h_i}\right)\right.$$

$$\left. \times \frac{L_i}{(\text{pwr})}\left(\frac{cD_i W_i}{r_i} + \frac{G_i W_i}{r_i}\right)\right\} \qquad (17.4)$$

where previously undefined terms are

- i = subscript identifying specific operation, areas, energy values, labor cost, etc.
- Σ = sum evaluated for all i operations
- c = constant, 0.27 [0.53]

The optimum power level is determined by minimizing the costs:

$$\text{pwr} = \sqrt{\Sigma\left\{\frac{100A_iE_i}{r_i(FC\%)t}\left(L_i \frac{K_iY_iV_iA_i}{(sc)_i(nt)_iU_ih_i}\right)\right\} + \Sigma\left\{\frac{100L_i}{(FC\%)t}\left(\frac{cD_iW_i}{r_2} + \frac{G_iW_i}{r_3}\right)\right\}} \qquad (17.5)$$

The machinery manager's duty in equipment selection is to minimize the cost of the complete system. Seldom does it happen that the tractor size necessary to pull the economically optimum plow or other large tillage implement is also the optimum size for the system as a whole. The value of Eq. 17.5 is that it includes the effects of all the operations in arriving at an optimum tractor size. The following example problem demonstrates the use of this equation.

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Example

A farm manager wants to determine the optimum machinery system that will include a large tractor for heavy field work, a smaller tractor for transport operations and utility work around the farmstead, and a self-propelled combine. The data sheets in Laboratory Exercise 19 serve to outline the solution procedure.

Cropping practice

Crop	Annual area	Value
Corn grain to be combined	100 ha [247 a]	$800/ha [$325/a]
Corn for ensilage	10 ha [24.7 a]	$800/ha [$325/a]
Soybeans to be combined	100 ha [247 a]	$500/ha [$200/a]
Hay, baled, 3 cuttings	10 ha [24.7 a]	$250/ha [$100/a]

Machines required

All corn area is to be processed, after combining, with a stalk chopper and disk harrow pulled in tandem (treated as one machine). Moldboard plowing for the soybean seedbed and chisel plowing for the corn seedbed is required. A field cultivator precedes the row crop planting. All row crops are rotary hoed once and cultivated once. The growing corn is sprayed once. The hay is to be made with a mower-conditioner, rake, and baler. The silage is cut with a forage harvester. Two varieties each of corn and soybeans are planted at different times to spread the timeliness demands on the machinery system.

The large tractor is used annually for

Manure loading	200 t	[220 T]
Crop drying	820 t	[900 T]

The small tractor is used annually to transport the following materials an average of 0.8 km [0.5 mi].

Fertilizer, Chemicals	82 t	[90 T]
Hay	111 t	[122 T]
Silage	300 t	[330 T]
Manure	200 t	[220 T]
Shelled corn	820 t	[900 T]
Soybeans	269 t	[296 T]

Load factors of 0.8 will be used for the large tractor and 0.9 for the small. The maximum size tractors available for purchase that meet the farm needs will be assumed to be 135 kW [180 HP] for the large tractor and 65 kW [87 HP] for the small. Diesel tractors will be purchased.

Large tractor selection (only Parts I and III apply)

Part I. For field operations; L = $8.00/hr, t = $465/kW [$347/HP], FC% = 16

Machine	Crop	A	E	r	K	YV	sc	nt	U	h	$\frac{100\,AE}{r(FC\%)t}\left(L+\frac{K(YV)A}{(sc)(nt)Uh}\right)$
Plow	soybeans	100 [247]	36 [19.5]	0.68	0.002	500 [200]	2	1	0.7	10	1078 [1921]
Chppr & disk	soybeans	100 [247]	16 [8.8]	0.77	0.002	500 [200]	2	1	0.6	10	456 [825]
Chisel	corn	110 [272]	31 [17]	0.68	0.002	800 [325]	2	1	0.6	10	1528 [2784]
Field cltvtr	soybeans	100 [247]	4.4 [2.4]	0.54	0.002	500 [200]	4	2	0.5	8	122 [219]
Field cltvtr	corn	110 [272]	4.4 [2.4]	0.54	0.002	800 [325]	4	2	0.5	8	163 [294]
Forage	corn silage	10 [25]	46 [25]	0.8	0.001	800 [325]	4	1	0.6	10	65 [117]
Baler	hay	30 [74]	9.2 [5]	0.3	0.010	250 [100]	2	3	0.55	12	122 [219]
Rotary hoe	soybeans	100 [247]	2 [1.1]	0.38	0.010	500 [200]	4	2	0.55	12	124 [224]
Rotary hoe	corn	110 [272]	2 [1.1]	0.38	0.010	800 [325]	4	2	0.55	12	192 [351]
										Total	3850 [6954]

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13.2 **Use Tables 13.1, 13.3 Use average fills for 500 and 300 rpm**

Fill area in auger: 3.14159/4 × (10^2 – 2.5^2) × 0.765 = 56.3 cm^2

3.14159/4 × (4^2 – 1^2) × 0.765 = 9.01 $in.^2$

Capacity: 400 rev/min × 10 cm/rev × 56.3 cm^2 × 719 kg/m^3 × 1 m^3/1000000 cm^3 × 60 min/hr = 9715 kg/hr

400 rev/min × 4in./rev × 9.01$in.^2$ × 44.8 lb/ft^3 × 1ft^3/1728$in.^3$ × 1 bu/56 lb × 60 min/hr = 400 bu/hr

NEW: What is the estimated power required for the above?

13.3 **a. Find type of fill; Use Eq. 13.4, Critical angle is:**

arc tan 100/(250-3) = 22.0° arc tan 4/(10 - 0.12) = 22°

- - - fill is triangular, use Eq. 13.1

b. Capacity: **25 × 10^2 × 1/(333.3 × 25 × tan 57.3°) = 0.193 m^3/min or 7.12 t/hr**

10 × 4^2 × 3.28/ (4.8 × 10 × tan 57.3°) = 7.02 ft^3/min or 8.09 T/hr

c. Power to lift grain:

7120 kg/hr × 4 m × 9.807 N/kg × 1 kW·sec/kN·m × 1 kN/1000 N × 1 hr/3600 secs = 0.078 kW

8.09 T/hr × 2000 lb/T × 1 HP·sec/550 ft·lb × 13.12 ft × 1 hr/3600 secs = 0.107 HP

Friction power:

grain: volume per cell: ½ × 10cm × 25cm × 10 cm/tan 57.3° = 802.5 cm^3

½ × 4 in. × 10 in. × 4 in./tan 57.3° = 51.4 $in.^3$

no. of cells: **4 m/sin 57.3° × 1 cell/.25 m = 19**

13.12 ft /in. 57.3° × 12 in./ft × 1 cell/10 in. = 18.7 or 19 cells

Total grain weight: **19 cells × 802.5 cm^3/cell × 616 kg/m^3 × 1 m^3/1000000 cm^3 = 9.39 kg**

19 cells × 51.4 $in.^3$/cell × 38.4 lb/ft^3 × 1 ft^3/1728 $in.^3$ = 21.7 lb.

Force perpendicular to conveyor bed: 9.39 kg × 9.807 N/kg × cos 57.3° = 49.75 N

21.7 lb × cos 57.3° = 11.7 lb

49.75 N × 0.35 × 1 m/sec × 1 kW·sec/kN·m × 1 kN/1000 m = 0.0174 kW

11.7 lb × 0.35 x 3.28 ft/sec × 1 HP·sec/550 ft·lb = 0.0244 HP

steel: Total chain weight: 2 kg/m × 9.807 N/kg × 4/sin 57.3° × 2 = 186.5 N

1.34 lb/ft × 13.12 ft/in. 57.3° × 2 = 41.78 lb

186.5 N × cos 57.3° × 0.57 × 1 m/sec × 1 kW·sec/kN·m × 1 kN/1000 N = 0.057 kW

41.78 lb × cos 57.3° × 0.57 × 3.28 ft/sec × 1HP·sec/550 ft·lb = 0.077 HP

Total Power: 0.078 + 0.0174 + 0.057 = 0.153 kW 0.107 + 0.0244 + 0.077 = 0.208 HP

NEW: What is the increase in capacity if the elevator is operated at the critical angle?

13.4 **a. Max. load carried at 360 kPa** [52 psi] **tire pressure:**

6 tires x 1500 kg/tire = 9000 kg, 9 tonne 6 tires x 3300 lb/tire = 19800 lb, 9.9 Tons

b. 1.15 x 9 = 10.35 tonne 1.15 × 9.9 = 11.39 tons

NEW: What would be the answers to the above for a soft tire pressure of 170 kPa [24 psi]**?**

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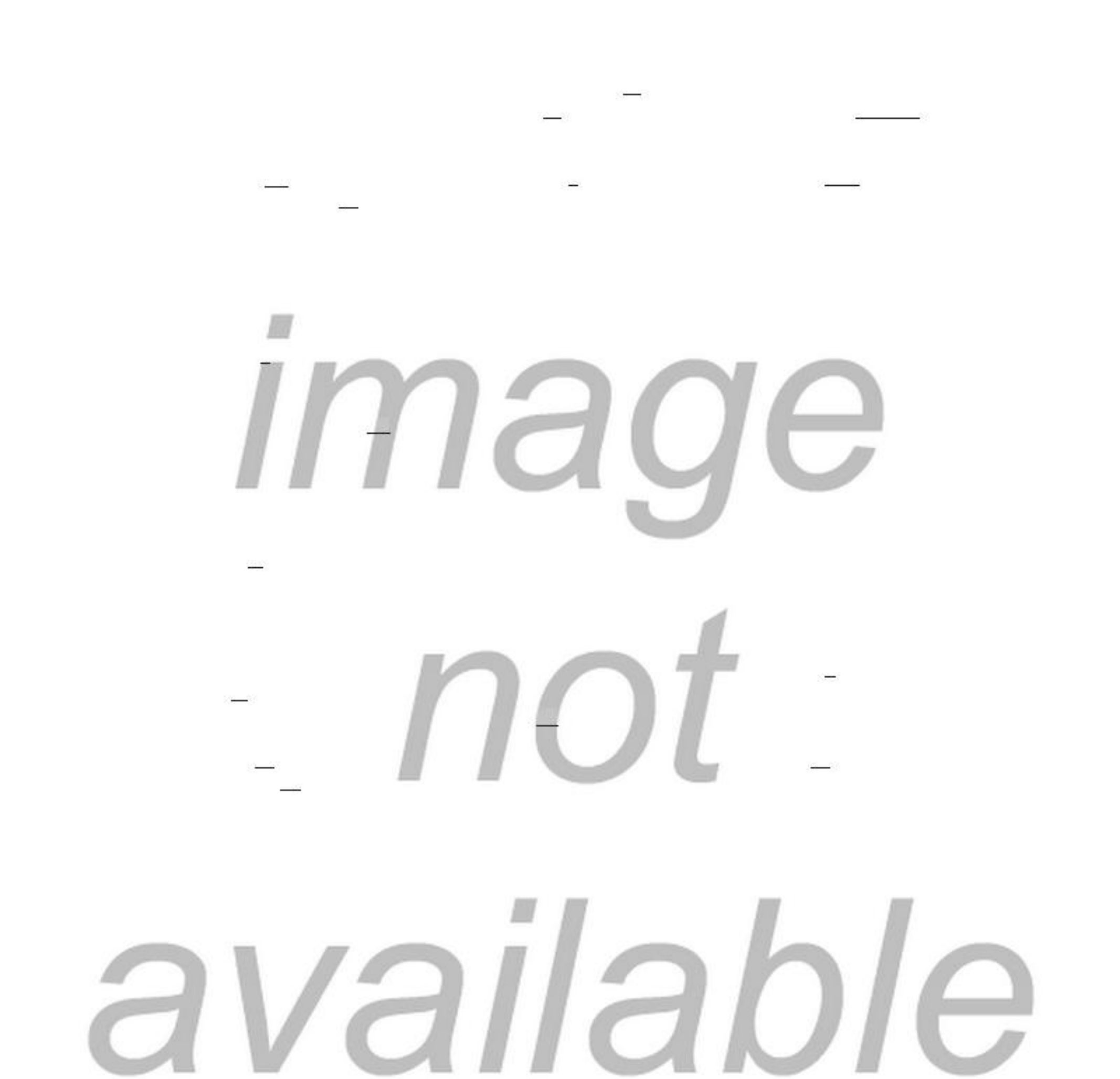
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